

mini_ker manual

for mini_ker version 102, January 02 2007

The TEF Collaboration

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Introduction

Mini_ker is a modeling tool, built especially in order to implement models written following the TEF (Transfer Evolution Formalism) formalism, a mathematical framework for system analysis and simulation. Mini_ker allows for timewise simulation, system analysis, adjoint computation, Kalman filtering and more.

Mini_ker uses a fortran preprocessor, `mortran`, designed in the 1970's, to ease model writing using dedicated specific languages. For example partial derivatives are symbolically determined by `mortran` macros in Mini-Ker. For the selection of another compile-time features set of preprocessor directives, the *cmz directives* are used. In most cases the user does not need to know anything about that preprocessing that occurs behind the scene, he simply writes down the equations of his model and he is done.

A comprehensive description of the TEF formalism is available on <http://www.lmd.jussieu.fr/ZOOM/doc/tef-GB-partA5.pdf>. The Mini_ker software is a reduced version of **ZOOM** (<http://www.lmd.jussieu.fr/zoom>), that can only handle a hundreds of variables, but is much easier to use.

Intended audience

The reader should have notions in system dynamics. Moreover a minimal knowledge of programmation and fortran is required. What is required is a basic understanding of variable types, affectation and fortran expressions.

Reading guide

The first chapter is a brief overview of the TEF. The following describes how to write, compile and run a model in Mini_Ker in its basic and comprehensive syntax. Reading the sections of this chapter up to the section *Symbolic model description* is required to know the syntax of model description in Mini_ker.

Reading up to the section *Controlling the run* is required to be able to use mini_ker. In this section it is assumed that Mini-Ker is properly setup. The installation instructions are in the appendix at Appendix A [Installation], page 48.

The next chapter describes advanced features, first a general introduction to features settings and then a description of other model description related features.

The next chapter describes system analysis tools available with mini_ker. The sections are independant and each describes how to use a specific feature. If you plan on using these features, you should also read Section 3.1 [Overview of feature setting], page 15.

A final chapter describes advanced features in a development environment using make,

In the appendix the instructions for the installation are described (see Appendix A [Installation], page 48).

Other Manuals and documentation

A programmers'Manual is available (in French), and can be asked for to any member of the collabration. See additional documents in <http://www.lmd.jussieu.fr/Zoom/doc> or ask for Research texts and articles to members.

1 An overview of the TEF formalism

The TEF (Transfer Evolution Formalism) is based on partitioning and recoupling of model subsystems. It allows the study of the coupling between subsystems by the means of linearization and time discretization.

1.1 Cell and Transfer equations

In the TEF, a model is mathematically represented by a set of equations corresponding to two kinds objects:

1. Cells which are elementary models and correspond to evolution equations such as:

$$\partial_t \eta(t) = g(\eta(t), \varphi(t))$$

Vector η represent the state variables of cells and the vector φ represent the dependent boundary conditions, *i.e.* the variables considered as boundary conditions by a cell, but depending upon the complete model state. This dependent boundary conditions are required to make the cells correspond to well-posed problems.

2. Transfers which are determined by constraint equations such as:

$$\varphi(t) = f(\eta(t), \varphi(t))$$

1.2 Linearization and discretization in the TEF

The relations between sub-systems is excessively difficult to exhibit when having to cope with non-linear system. In the TEF, the TLS (Tangent Linear System) is constructed along the trajectory. One considers the system over a small portion along the trajectory, say between t and $t + \delta t$. The variation $\delta\eta$ of η and $\delta\varphi$ of φ is obtained through a Pad approximation of the state-transition matrix. The final form of the algebraic system is closed to the classical Crank-Nicolson scheme:

$$\begin{pmatrix} A & B \\ -C^+ & I - D \end{pmatrix} \begin{pmatrix} \delta\eta \\ \delta\varphi \end{pmatrix} = \begin{pmatrix} \Gamma \\ \Omega \end{pmatrix}$$

The blocks appearing in the Jacobian matrix are constructed with partial derivative of f and g , and with δt . From this system the elimination of $\delta\eta$ leads to another formulation giving the coupling between transfers, and allows for the $\delta\varphi$ computation. The $\delta\varphi$ value is then substituted in $\delta\eta$ to complete the time-step solving process.

2 Mini_ker model programming

Mini_Ker works by combining the model specification code given by the user and other source files provided in the package. The code is assembled, preprocessed, compiled, linked and the resulting program can be run to produce the model trajectory and dynamic analysis.

The code provided in the package contains a principal program, library subroutines and pieces of code called *sequences* combined with the different codes. Among these sequences some hold the code describing the model and are to be written by the user (sequences are similar to Fortran include files).

2.1 General structure of the code

The sequences used to enter model description hold the vector dimensions, mathematical formulae for each cell and transfer component, dedicated derived computations, and time-step steering. During the code generation stage, cmz directives are preprocessed, then the user pseudo-Fortran instructions are translated by `mortran` using macros designed to generate in particular all Fortran instructions that compute the Jacobian matrices used in TEF modelling.

A first users' sequence to program is: 'dimetaphi' where the model dimensions are given, for the two vector-array `eta(.)` for cells and `ff(.)` for transfers (see Section 2.2.2 [Entering model size], page 4). The sequence 'zinit' contains the mathematical formulation of the model (see Section 2.2.3 [Model equation and parameters], page 4). Another sequence 'zsteer' is introduced at the end of the time step advance of the simulation, where the user can monitor the time step values and printing levels, and perform particular computations etc. (see Section 2.5.1 [Executing code at the end of each time step], page 13).

2.2 Mini_ker programming illustrated

The general TEF system writes:

$$\begin{aligned}\partial_t \eta(t) &= g(\eta(t), \varphi(t)) \\ \varphi(t) &= f(\eta(t), \varphi(t))\end{aligned}$$

To illustrate the model description in Mini-Ker a simple predator-prey model of Lotka-Volterra is used. This model can be written in the following TEF form:

$$\begin{cases} \partial_t \eta_{prey} = a\eta_{prey} - a\varphi_{meet} \\ \partial_t \eta_{pred} = -c\eta_{pred} + c\varphi_{meet} \end{cases}$$

$$\varphi_{meet} = \eta_{prey}\eta_{pred}$$

with two cell equations, *i.e.* state evolution of the prey and predator groups, and one transfer accounting for the meeting of individuals of different group.

2.2.1 All you need to know about mortran and cmz directives

The first stage of code generation consists in cmz directives preprocessing. Cmz directives are used for conditional selection of features, and sequence inclusion. At that point you don't need to know anything about these directives. They are only useful if you want to take advantage of advanced features (see Section 3.9 [Programming with cmz directives], page 28).

The code in sequences is written in Mortran and the second stage of code generation consists in mortran macro expansion. The mortran language is described in its own manual, here we only explain the very basics which is all you need to know to use mini_ker. Mortran basic instructions are almost Fortran, the differences are the following:

- The code is free-form, and each statement should end with a semi-colon ;.
- Comments may be introduced by an exclamation mark ! at the beginning of a line, or appear within double quotes " in a single line.
- It is possible to use blocs, for do or if statement for example, and they are enclosed within brackets '<' and '>'.

The following fictitious code is legal mortran:

```
real
  param;
  param = 3.; ff(1) = ff(3)**eta(1);      "a comment"
  ! a line comment
  do inode=1,n_node <eta_move(inode)=0.01; eta_speed(inode)=0.0;>;
```

Thanks to mortran the model code is very simply specified, as you'll see next.

2.2.2 Entering model size

The dimension of the model is entered in the sequence 'dimetaphi', using the fortran parameter `np` for `eta(.)` and `mp` for `ff(.)`. For this model, we have two cell components and only one transfer.

```
parameter (np=2,mp=1);
```

You should not change the layout of the parameter statement as the mortran preprocessor matches the line.

You also have to provide other parameters even if you don't have any use for them. If you don't it will trigger fortran errors. It includes the `maxstep` parameter that can have any value but 0, `lp` and `mobs` that should be 0 in the example, and `nxp`, `nyp` and `nzp` that should also be 0. The layout is the following:

```
parameter (np=2,mp=1);
parameter (mobs=0);

parameter (lp=0);
parameter (maxstep=1);
```

2.2.3 Entering model equation and parameters

The model equation and parameters and some mini_ker parameters are entered in the 'zinit' sequence. The whole layout of the model is given before detailing the keywords.

```

!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
! Parameters
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
  real apar,bpar;          "optional Fortran type declaration"

! required parameters
  dt=.01;                  "initial time-step"
  nstep=10 000;           "number of iterations along the trajectory"
  time=0.;                "time initialisation "

! model parameters
  apar = 1.5;
  cpar = 0.7;

! misceallaneous parameters
  modzprint = 1000;      "printouts frequency"

print*, '*****';
print*, 'Lotka-Volterra model with parameters as: ';
z_pr: apar,bpar;
print*, '*****';

!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
! Transfer definition
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
! meeting of prey and predator
  f_set Phi_tef(1) = eta(1)*eta(2);          "transfer definition"

!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
! Cell definition
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
! eta(1) : pray
! eta(2) : predator

f_set deta_tef(1) = apar*eta(1)-apar*ff(1);  "cell time advance"
f_set deta_tef(2) = - cpar*eta(2) + cpar*ff(1); "definition      "

!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
! Initial states
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
  eta(1) = 1.;
  eta(2) = 1.;

;
  OPEN(50,FILE='title.tex',STATUS='UNKNOWN');  "title file"
  write(50,5000) apar,cpar;
5000;format('Lotka-Volterra par:',2F4.1);

```

Variables and model parameters

The following variables are mandatory:

dt The time step.
time Model time initialisation.
nstep Number of iterations along the trajectory.

There are no other mandatory variables. Some optional variables are used to monitor the printout and output of results of the code. As an example, the variable `modzprint` is used to set the frequency of the printout of the model matrix and vectors during the run (see Section 2.5.2 [Controlling the printout and data output], page 14).

User's defined variable and Fortran or Mortran instructions can always be added for intermediate calculus. To avoid conflict with the variables of the `mini_ker` code, the rule is that a users symbol must not have characters 'o' in the first two symbol characters.

In the predator-prey example there are two model parameters. The fortran variables are called here `apar` for *a* and `cpar` for *c*. If a Fortan type definition is needed, it should be set at the very beginning of 'zinit'. The predator-prey code variable initializations finally reads

```
!%%%%%%%%%%
! Parameters
!%%%%%%%%%%
  real apar,bpar;          "optional Fortran type declaration"

  dt=.01;
  nstep=10 000;
  time=0.;

! model parameters
  apar = 1.5;
  cpar = 0.7;

  modzprint = 1000;
```

Model equations

The model equations for cells and transfers are entered using a mortran macro, `f_set`¹, setting the `eta(.)` evolution with `deta_tef(.)` and the transfer definitions `ff(.)` with `Phi_tef(.)`.

`f_set Phi_tef(i) = f(eta(.),ff(.))` [Macro]
 This macro defines the transfer *i* static equation. **f** is a fortran expression which may be function of cell state variables, 'eta(1)'... 'eta(np)' and transfers 'ff(1)'... 'ff(mp)'.

¹ `fun_set`, or equivalently `f_set`, is a general mortran macro associating a symbol with a fortran expression. Here, it is the name of the symbol (`eta`) that has a particular meaning for the building of the model.

In the case of the predator-prey model, the transfer definition for φ_{meet} is:

```
f_set Phi_tef(1) = eta(1)*eta(2);
```

```
f_set deta_tef(i) = g(eta(i),ff(.)) [Macro]
```

This macro defines the cell state component i time evolution model. g is a expression which may be function of cell state variables, 'eta(1)'...'eta(np)' and transfers 'ff(1)'...'ff(mp)'.

The two cell equations of the predator-prey model are, with index 1 for the prey (η_{prey}) and index 2 for the predator (η_{pred}):

```
f_set deta_tef(1) = apar*eta(1)-apar*ff(1);
f_set deta_tef(2) = - cpar*eta(2) + cpar*ff(1);
```

The whole model is:

```
!%%%%%%%%%%
! Transfer definition
!%%%%%%%%%%
! rencontres (meeting)
    f_set Phi_tef(1) = eta(1)*eta(2);

!%%%%%%%%%%
! Cell definition
!%%%%%%%%%%
! eta(1) : prey
! eta(2) : predator

    f_set deta_tef(1) = apar*eta(1)-apar*ff(1);
    f_set deta_tef(2) = - cpar*eta(2) + cpar*ff(1);
```

Starting points

The cells equations require state initial conditions. In some case, the transfers may also need starting points although they are determined from the cell values.

In the predator-prey model the starting points for cells are:

```
!      initial state
!      -----
    eta(1) = 1.;
    eta(2) = 1.;
```

When there is a non trivial implicit relationship between the transfers in the model, it may be usefull or even necessary to set some transfers to non-zero values. This difficulty is only relevant for the very first step of the simulation and will be used as a first guess of φ . The uninitialized transfers having a default compiler-dependant (often zero) value, an initialization to another value may help avoiding singular functions or matrix and ensure convergence in the Newton algorithm used to solve the transfer implicit equation.

title file

For some graphics generation, a file with name 'title.tex' is required which sets the title. The following instructions take care of that:

```

OPEN(50,FILE='title.tex',STATUS='UNKNOWN');
write(50,5000) apar,cpar;
5000;format('Lotka-Volterra par:',2F4.1);

close(50);

```

In that case the parameter values are written down, to differentiate between different runs.

2.3 Symbolic model description

The preceding description of the model has been given to grab the very kernel of the Mini-Ker principles. The following symbolic description of a model is preferable, because it is not only more flexible, but also generates more readable files and comments along a run. It nevertheless will eventually generate the same Fortran code as the basic language, even if the 'dimetaphi' sequence is automatically generated. In the symbolic description, the coordinate of the states `eta(.)` and the transfers `ff(.)` are not index with numbers but are given a name. The model equations are entered in two mortran blocks, one for the transfers, the other for the cell components.

`set_Phi` introduces the transfer block, `set_eta` introduces the cell block. In each block the couples variable-function are specified. For transfers the function defines the transfer itself while for cells the function describes the cell evolution. The variable is specified with `var:`, the function is defined with `fun:`.

The same above example can be equivalently entered as:

```

!%%%%%%%%%%
! Transfer definition
!%%%%%%%%%%
! rencontre (meeting)
set_Phi
< var: ff_interact, fun: f_interact = eta_prey*eta_pred;
>;

!%%%%%%%%%%
! Cell definition
!%%%%%%%%%%

set_eta
< var: eta_prey, fun: deta_prey =  apar*eta_prey - apar*ff_interact;
   var: eta_pred, fun: deta_pred = - cpar*eta_pred + cpar*ff_interact;
>;

```

Whenever the user is not concerned with giving a specific name to a function, it is possible to specify the equation only with `eqn:`. Therefore the user may replace an instruction as:

```

var: ff_dump,
fun: f_dump = - rd*(eta_speed - eta_speed_limiting);
with:
eqn: ff_dump = - rd*(eta_speed - eta_speed_limiting);

```

In that case, the unnamed function will take the name of the defined variable preceded by the '\$' sign: `$ff_dump`.

It is also possible to use the basic instructions `f_set` in the same program, but one has to be careful and do not overwrite the same vector components as the one entered using the `set_` instructions.

The correspondence with basic components are printed out at execution time as explained in Section 2.4.3 [Running a simulation and using the output], page 11. Also, a `Model.hlp` is generated that recalls the basic names and equations of the model. It may be noted that whenever the order of variable-functions is the same between indexed declaration and symbolic, the two generated Fortran code are almost identical.

2.4 Setting and running a model

In this section it is assumed that a programming environment has been properly setup. This environment may use either `cmz` or `make` to drive the preprocessing and compilation. You can skip the part related with the environment you don't intend to use.

For instructions regarding the installation, see Appendix A [Installation], page 48.

2.4.1 Setup a model and compile with `cmz`

The user defined sequences are 'KEEP' in the `cmz` world. The most common organization is to have a `cmz` file in a subdirectory of the directory containing the `mini_ker` `cmz` file. In this `cmz` file there should be a 'PATCH' called 'zinproc' with the KEEPs within the patch. The KEEPs must be called '\$zinit' and '\$dimetaphi'.

From within `cmz` in the directory of your model the source extraction, compilation and linking will be triggered by a `mod` command. This macro uses the 'selseq.kumac' information to find the `mini_ker` `cmz` file. `mod` shall create a directory with the same name than the `cmz` file, 'mymodel/' in our example. In this directory there is another directory 'cfs/' containing the sources extracted from the `cmz` file.

The file 'mymodel_o.tmp' contains all the mortran code generated by `cmz` with the sequences substituted, including the '\$zinit' and '\$dimetaphi' sequences (assembled code). The fortran produced by the preprocessing and splitting of this file is in files with the traditional '.f' suffix. The principal program is in 'principal.f'. An efficient way of getting familiar with `mini_ker` methods is looking at the 'mymodel_o.tmp' where all sequences and main Mortran instructions are gathered. Symbolic derivation is noted as `F_D(expression)(/variable)`, and the resulting Fortran code is in 'principal.f'.

`mod` also triggers compilation and linking. The object files are in the same 'cfs/' directory and the executable is in the 'mymodel/' directory, with name 'mymodel.exe'.

2.4.2 Setup a model and compile with `make`

With `make`, the sequences are files ending with '.mti' (for mortran include files), called 'zinit.mti' and 'dimetaphi.mti'. They are included by `mortran` in other source files. You also need a 'Makefile' to drive the compilation of the model.

If you don't need additional code or libraries to be linked with your model you have two alternatives.

1. The simplest alternative is to run the `start_miniker` script with the model file name as argument. It should copy a 'zinit.mti' and 'dimetaphi.mti' files ready to be edited

and a Makefile ready to compile the model. For the predator prey model, for example, you could run

```
$ start_miniker predator
```

2. Otherwise you can copy the Makefile from 'template/Makefile' in the directory containing the sequences. You should then change the compiled model file name, by changing the value of the `model_file_name` variable to the name of your choice in the Makefile. It is set to 'mymodel' in the template. For the predator-prey model, it could be set like

```
model_file_name = predator
```

If you want the executable model file to be built in another directory, you could set

```
model_file_name = some_dir/predator
```

The other items set in the default Makefile should be right.

The preprocessing and the compilation are launched with

```
make all
```

The mortran files are generated by the `cmz` directive preprocessor from files found in the package source directories. The mortran files end with '.mtn' for the main files and '.mti' for include files. They are output in the current directory. The mortran preprocessor then preprocess these mortran files and includes the sequences. The resulting fortran code is also in the current directory, in files with a '.f' suffix. Some fortran files ending with '.F' may also be created by the `cmz` directive preprocessor. The object files resulting from the compilation of all the fortran files (generated from mortran or directly from fortran files) are there too.

In case you want to override the default sequences or a subroutine file you just have to create it in your working directory along with the 'zinit.mti' and 'dimetaphi.mti'. For example you could want to create or modify a 'zsteer.mti' file (see Section 2.5.1 [End of time step], page 13), a 'zcmd_law.mti' file (see Section 4.2.2 [Control laws], page 33), a 'monitor.f' file (see Section 3.2.1 [Turning the model into a subroutine], page 15) to take advantage of features presented later in this manual.

More in-depth discussion of using make to run Mini_ker is covered in Chapter 5 [Advanced use of mini_ker with make], page 43. For example it is also possible to create files that are to be preprocessed by the `cmz` directive preprocessor, this advanced use is more precisely covered in Section 3.9 [Programming with `cmz` directives], page 28.

2.4.3 Running a simulation and using the output

Once compiled the model is ready to run, it only has to be executed. On standard output informations about the states, transfers, tangent linear system and other jacobian matrices are printed. For example the predator-prey model could be executed with:

```
./predator > result.lis
```

In case of a model entered symbolically (see Section 2.3 [Symbolic model description], page 8) the correspondance between the symbolic variables and the basic vectors and functions are printed at run time:

```
----- Informing on Phi definition -----
  Var-name,          Function-name,      index in ff vector
          ff_interact          f_interact  1
-----
```

```
----- Informing on Eta definition -----
  Var-name,          Function-name,      index in eta vector
          eta_prej          deta_prej  1
          eta_pred          deta_pred  2
-----
```

A summary of the model equations are in 'Model.hlp' file. For the same example:

```
===== set_Phi

  1 ff_interact f_interact          eta_pray*eta_pred
===== set_Eta

  1 eta_pray    deta_pray          apar*eta_pray-apar*ff_interact
  2 eta_pred    deta_pred          -cpar*eta_pred+cpar*ff_interact
```

when other general functions are specified with `f_set`, it can appear also in the same help file when replaced by `fun_set`.

As far as possible, all data printed in the listing are associated with a name related to a variable. Here is an extract:

```
Gamma :-8.19100E-02-1.42151E-01 3.87150E-02
          eta_courant eta_T_czcx eta_T_sz
-----
Omega : 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
          courant_L   T_czcx      Psi_Tczc   Psi_Tsz
-----
```

for the two known vectors of the system, and:

```
>ker : Matrice de couplage      4 4 4 4
courant_L Raw(1,j=1,4):   1.000    -9.9010E-03  0.000      0.000
T_czcx    Raw(2,j=1,4): -2.7972E-02   1.000      0.000      9.9900E-04
Psi_Tczcx Raw(3,j=1,4):  0.1605     9.7359E-02  1.000     -5.7321E-03
Psi_Tsz   Raw(4,j=1,4):  0.000     -0.1376     5.7225E-03  1.000
          Var-Name      courant_L   T_czcx      Psi_Tczc   Psi_Tsz
-----
```


where the “couplage” (coupling matrix) is given that corresponds to the matrix coupling the four transfer components after $\delta\eta$ has been eliminated from system. It is computed in the subprogram ‘`oker`’ (for kernel) which solves the system.

Basic results are output in a set of ‘.data’ files. Each data file has the `time` variable values as first column. The first line (or two lines) describes the column in the `gnuplot` format¹. Following columns give the values of `eta(.)` in ‘`res.data`’, `dEta(.)` in ‘`dres.data`’ – the step by step variation of `eta(.)` – and `ff(.)` in ‘`tr.data`’.

Along the simulation the TEF Jacobian matrices are computed. A transfer variables elimination process also leads to the definition of the classical state advance matrix of the system (the corresponding array is `aspha(.,.)` in the code). This matrix is output in the file ‘`aspha.data`’ that is used to post-run dynamics analyses. The matrix columns are written column wise on each record. See Section 4.5 [Stability analysis of fastest modes], page 40. See Section 4.6 [Generalized tangent linear system analysis], page 41. It is not used in the solving process.

Other ‘.data’ files will be described later.

At the begining of a run, the help file ‘`Model.hlp`’ is generated for global checkiing of the model. In the example, it is:

```

===== set_Phi
      1 ff_interact      f_interact      eta_pray*eta_pred
===== set_Eta
      1 eta_pray        deta_pray      apar*eta_pray-apar*ff_interact
      2 eta_pred        deta_pred      -cpar*eta_pred+cpar*ff_interact

```

2.4.4 Doing graphics

The format of the ‘.data’ files are coherent with GNU graphics, that is the data are simply separated with spaces. The files can be vizualised with `gnuplot`, for example. To plot `eta(n)`, the `gnuplot` statement is:

```
plot "res.data" using 1:(n+1)
```

The similar one for `ff(n)`:

```
plot "tr.data" using 1:(n+1)
```

For people using PAW, the CERN graphical computer code, `mini_ker` prepares `kumacs` that allow to read process the ‘.data’ files in the form of *n-tuples* (see the *PAW manual* for more information). In that cas, the flag `sel paw` has to be gievn in the ‘`selsequ.kumac`’. The generated n-tuples are ready to use only for vector dimension of at most 10 (including the variable `time`). These `kumacs` are overwritten each time the model is run. Usually, `gnuplot` has to be preferred, but when using surfaces and histograms, PAW is better. The ‘`gains.f`’ (and ‘`go.xqt`’ is provided as an example in the Mini-Ker files.

2.5 Controlling the run

It is possible to add code that will be executed at the end of each time step. It is also possible to specify which time step leads to a printout on standard output. For maximal

¹ ‘`dres.data`’ has another time related variable as second column: `dt`, the time step that can vary in the course of a simulation.

control, the code running the model may be turned into a subroutine to be called from another Fortran program, this possibility is covered in Section 3.2 [Calling the model code], page 15.

2.5.1 Executing code at the end of each time step

The code in the sequence 'zsteer' is executed at the end of each time step. It is possible to change the time step length (variable `dt`) verify that the non linearity are not too big, or perform discontinuous modifications of the states. One available variable `res` might be useful for time step monitoring. At the end of the time step, as soon as φ has been computed, a numerical test is applied on a pseudo relative quadratic residual between $\varphi = f(\eta(t-dt) + d\varphi)$ (`ffl`), where $d\varphi$ is given by the system resolution in `ker`, and $\varphi = f(\eta), \varphi$, Fortran variable (`ff`):

```
! =====
! test linearite ffl - ff
! =====
if (istep.gt.1)
< res=0.; <io=1,m; res = res +(ffl(io)-ff(io))**2/max(one,ff(io)*ff(io)); >;
  if (res .gt. TOL_FFL)
    < print*, '*** pb linearite : res > TOL_FFL a istep', istep, res, ' > ', TOL_FFL;
    do io=1,m < z_pr: io, ffl(io), ff(io)-ffl(io); >;
  >;
>;
```

This test hence applies only for non linearities in transfer models. Nevertheless, `res` might be useful to monitor the time step `dt` in `ZSTEER` and eventually go backward one step (`goto :ReDoStep`). This can more appropriately be coded in the (empty) sequence `ZSTEP`, inserted just before time-advancing states and time variables in 'principal'.

It is also possible to fix the value of the criterium `TOL_FFL` in 'zinit' different from its default value of 10^{-3} – independent of the Fortran precision.

Many other variables are available, including

```
istep      The step number;
couplage(.)
           The TEF coupling matrix between transfers;
the Jacobian matrices
           H, Bb, Bt, D;
the state advance matrix
           aspha;
and the variables increments
           dneta, dphi;
```

One should be aware of that the linearity test concerns the preceding step. We have yet no example of managing the time-step to show.

2.5.2 Controlling the printout and data output

The printout on standard output is performed if the variable `zprint` of type `logical` is true. Therefore it is possible to control this printout by setting `zprint` false or true. For example the following code, in sequence `'zsteer'`, triggers printing for every `modzprint` time step and the two following time steps:

```
ZPRINT = mod(istep+1,modzprint).eq.0;  
Zprint = zprint .or. mod(istep+1,modzprint).eq.1;  
Zprint = zprint .or. mod(istep+1,modzprint).eq.2;
```

The data output to `'data'` files described in Section 2.4.3 [Running a simulation and using the output], page 11 is performed if the `logical` variable `zout` is true. For example the following code, in `'zsteer'`, triggers output to `'data'` files every `modzout` step.

```
Zout = mod(istep,modzout).eq.0;
```

3 Advanced mini_ker programming

3.1 Overview of additional features setting

It is possible to enable some features by selecting which code should be part of the principal program. Each of these optionnal features are associated with a *select flag*. For example double precision is used instead of simple precision with the ‘double’ select flag, the model is a subroutine with the select flag ‘monitor’, the Kalman filter code is set with ‘kalman’ and the 1D gridded model capabilities are associated with ‘grid1d’. To select a given feature the cmz statement `sel select_flag` should be written down in the ‘selseq.kumac’ found in the model directory. With make either the corresponding variable should be set to 1 or it should be added to the SEL make variable, depending on the feature.

Other features don’t need different or additional code to be used. Most of the features are enabled by setting specific logical variables to ‘.true.’. This is the case for `zback` for the adjoint model, `zcommand` if the command is in a file and `zlaw` if it is a function and `zkalman` for the Kalman filter. These select and logical flags are described in the corresponding sections.

In cmz an alternative of writing select flags to ‘selseq.kumac’ is to drive the compilation with `smod sel_flag`. In that case the *sel_flag* is selected and the files and executable goes to a directory named ‘sel_flag’.

The select flags are taken into account during cmz directives preprocessing. Therefore you have the possibility to use these flags to conditionnaly include pieces of code. In most cases you don’t need to include code conditionally yourself though, but if you want to, this is covered in Section 3.9 [Programming with cmz directives], page 28.

3.2 Calling the model code

When the model code is a subroutine, it can be called from another fortran program unit (or another program), and the model will be run each time the subroutine is called. This technique could be used, for example to perform optimization (see Section 4.2 [Adjoint model and optimisation with mini_ker], page 32), or to run the model with different parameters.

3.2.1 Turning the model into a subroutine

With cmz, one has to do a

```
sel monitor
```

in the ‘selseq.kumac’ file and create the KEEP that call the model code. See Section 3.1 [Selecting features], page 15.

With make ‘monitor’ should be added to the SEL variable in the ‘Makefile’, for example:

```
SEL = monitor
```

A file that call the principal subroutine should also be written, using the preferred language of the user. The additional object files should then be linked with the mini_ker objects. To that aim they may be added to the `miniker_user_objects` variable.

3.2.2 Calling the model subroutine

The model subroutine is called ‘principal’ and is called with the following arguments:

`principal` (*Cost*, *ncall*, *integer_flag*, *file_suffix*, *info*, *idxerror*) [Subroutine]

Where *Cost* is a real number, **real** or **double precision**, and is set by the **principal** subroutine. It holds the value of the cost function if such function has been defined (the use and setting of a cost function is covered later, see Section 4.2.3 [Cost function coding and adjoint modeling], page 34). *ncall* is an integer which corresponds with the number of call to **principal** done so far, it should be initialized to 0 and its value should not be changed, as it is changed in the **principal** subroutine. *integer_flag* is an integer that can be set by the user to be accessed in the **principal** subroutine. For example its value could be used to set some flags in the ‘zinit’ sequence. *file_suffix* is a character string, that is suffixed to the output files names instead of ‘.data’. If the first character is the null character ‘char(0)’, the default suffix, ‘.data’ is appended. *info* and *idxerror* are integer used for error reporting. *idxerror* value is 0 if there was no error. It is negative for an alert, positive for a very serious error. The precise value determines where the error occurred. *info* is an integer holding more precise information about the error. It is usually the information value from lapack. The precise meaning of these error codes is in table 3.1.

Source of error or warning	info	idxerror
state matrix inversion in ker	inversion	1
time advance system resolution in ker	system	2
transfer propagator, $(I - D)$ inversion	inversion	3
kalman analysis state matrix advance in phase space, $(I - D)$ inversion	inversion	21
kalman analysis variance covariance matrix non positive	Choleski	22
kalman analysis error matrix inversion	inversion	23
kalman error matrix advance	system	24
transfers determination linearity problem for transfers		-1
transerts determination Newton D_loop does not converge		-2

table 3.1: Meaning of error codes returned by principal.

In general more information than the provided arguments has to be passed to the **principal** subroutine, in that case a **common** block, to be written in the ‘dimetaphi’ sequence can be used.

3.3 Describing 1D gridded model

Specific macros have been built that allow generic description of 1D gridded models. Because of the necessity of defining left and right limiting conditions, the models are partitioned in three groups for cell and transfer components. In the following example, a chain of masselottes linked by springs and dumps is bounded to a wall on the left, and open at right. The TEF formulation of the problem is written in the phase space (position-shift, velocity) for node k , with bounding conditions:

$$\begin{cases} \partial_t \eta_k^{pos} = \eta_k^{vel} \\ \partial_t \eta_k^{vel} = (\varphi_k^{spr} - \varphi_{k+1}^{spr} + \varphi_k^{dmp} - \varphi_{k+1}^{dmp}) / m_k \end{cases}$$

$$\begin{cases} \varphi_k^{spr} = -k_k(\eta_k^{pos} - \eta_{k-1}^{pos}) \\ \varphi_k^{spr} = -d_k(\eta_k^{vel} - \eta_{k-1}^{vel}) \end{cases}$$

$$\begin{cases} \eta_0^{pos} = 0 \\ \eta_0^{vel} = 0 \\ \varphi_{N+1}^{spr} = 0 \\ \varphi_{N+1}^{dmp} = 0 \end{cases}$$

where m_k is the mass of node k , r_k and d_k the rigidity of springs and dumping coefficients. There are N nodes in the grid, from 1 to N , and two nodes outside of the grid, a limiting node 0, and a limiting node $N + 1$. The limiting node corresponding with node 0 is called the *down* node, while the limiting node corresponding with node $N + 1$ is called the *up* node. Other models not part of the 1D grid may be added if any.

To enable 1D gridded models, one should set the select flag ‘`grid1d`’ in ‘`selseq.kumac`’, like

```
sel grid1d
```

3.3.1 Setting dimensions for 1D gridded model

In that case the number of nodes, the number of states and tranferts per node, and the number of limiting transfers and states are required. These dimensions has to be entered in the ‘`DimEtaPhi`’ sequence. The parameters for cells are

- `n_node` Number of cell nodes in the 1D grid.
- `n_dwn` Number of limiting cells with index -1, *i.e.* number of cells in the limiting down node.
- `n_up` Number of limiting cells with index +1, *i.e.* number of cells in the limiting up node.
- `n_mult` Number of cells in each node (multiplicity).

The parameters for transfers, are similarly `m_node`, `m_dwn`, `m_up`, `m_mult`. The layout of their declaration should be respected as the precompiler matches the line. Also this procedure is tedious, it should be selected for debugging processes (use the flag `sel dimetaphi` in “`selseq.kumac`”). Otherwise, the dimensioning sequence will be automatically generated,

which is smart but can lead to difficulty in interpreting syntax errors. Once a model is correctly entered, turn off the sel flag and further modifications will automatically generate the proper dimensions. The correctness of dimensioning should nevertheless always be checked in `principal.f`, where you can also check that null valued parameters as `lp`, `mobs`, `npx` will suppress parts of the code - this is signaled as Fortran comment cards.

In our example, there are three grids of cell and transfer variables (`n_node=m_node=3`). There are two cells and two transfers in each node (`n_mult=2` and `m_mult=2`). There is no limiting condition for the states in the down node therefore `n_up=0`. There is no transfer for the first limiting node, and therefore `m_dwn=0`. There are two states in the limiting node 0, the down node, `n_dwn=2`, and two transfers in the limiting last node the node up, and `m_up=2`:

```
! ++++++
! nodes parameters, and Limiting Conditions (Low and High)
! ++++++
      parameter (n_node=3,n_dwn=2,n_up=0,n_mult=2);
      parameter (m_node=3,m_dwn=0,m_up=2,m_mult=2);
! -----
```

3.3.2 1D gridded Model coding

The model code and parameters go in the 'zinit' sequence.

Parameters

A value for the mini_ker parameters and the model parameters should be given in 'zinit', in our example we have

```
!%%%%%%%%%%
! Parameters
!%%%%%%%%%%
real rk(n_node),rd(n_node),rmass1(n_node);

data rk/n_node*1./;
data rd/n_node*0.1/;
data rmass1/n_node*1./;
      dt=.01;
      nstep=5 000;
      modzprint = 1000;
      time=0.;
```

Limiting conditions

The limiting states and transfer variables and the corresponding equations are declared using the symbolic model description (see Section 2.3 [Symbolic model description], page 8). There are four mortran blocks for `node` and `up` and `down`, both for states and transfers:

```
set_dwn_eta
      down node cells

set_up_eta
      up node cells
```

```
set_dwn_phi
    down node transfers
```

```
set_up_phi
    up node transfers
```

The following scheme illustrates the example:

```
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%=====
! Maillage convention inode
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
!                               Open ended
!(2 Down   Phi   Eta                               (n_node)
! Eta) \ |   .----- .----- .----- /
! wall \|-\\/\|-|   |-\|\\/\|-|   |   . . . -|   |-\|\\/\|-| dummy
! pos  \|--***--| 1 |--***--| 2 |   . . . -|  n |--***--| Phis
! speed \ |   1 |-----| 2 |-----|   n |-----| n+1  \ (2 Up Phi)
!
```

Two states are associated with the down node, they correspond to the position and speed of the wall. As the wall don't move these states are initialized to be 0, and the cells are stationary cells, therefore these values remain 0.

```
! Down cells (wall)
! -----
eta_pos_wall = 0; eta_speed_wall = 0.;

set_dwn_eta
< var: eta_pos_wall, fun: deta_pos_wall = 0.;
  var: eta_speed_wall, fun: deta_speed_wall= 0.;
>;
```

There are 2 limiting transfers in the up node. They correspond with an open end and are therefore set to 0.

```
! limiting Transfers : dummy ones
! -----
set_Up_Phi
< var:ff_dummy_1, fun: f_dummy_1=0.;
  var:ff_dummy_2, fun: f_dummy_2=0.;
>;
```

Starting points

The cell node state values are initialized. They are in an array indexed by the `inode` variable. In the example the variable corresponding with position is `eta_move` and the variable corresponding with speed is `eta_speed`. Their initial values are set with the following mortran code

```
!-----
! Initialisation
!-----
;
do inode=1,n_node <eta_move(inode)=0.01; eta_speed(inode)=0.0;>;
```

If any transfer needs to be given a first-guess value, this is also done using `inode` as the node index.

Grid node equations

Each node is associated with an index `inode`. It allows to refer to the preceding node, with `inode-1` and the following node `inode+1`. The node states are declared in `set_node_Eta` block and the transfers are in `set_node_Phi` blocks.

In the example, the cells are declared with

```
! node cells
! -----
;
set_node_Eta
< var: eta_move(inode), fun: deta_move(inode) = eta_speed(inode);
  var: eta_speed(inode),
  fun: deta_speed(inode) = rmassm1(inode)
                                *( - ff_spring(inode+1) + ff_spring(inode)
                                  - ff_dump(inode+1) + ff_dump(inode)
                                );
>;
```

Note that the `inode` is dummy in the `var:` definition and can as well be written as: `var: eta_move(.)`.

The transfers are (`ff_spring` corresponds with springs and `ff_dump` with dumps):

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! Transfer definition
!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! node transfers
! -----
! convention de signe spring : comprime:= +
set_node_Phi
< var: ff_spring(.),
  fun:
    f_spring(inode)= -rk(inode)*(eta_move(inode) - eta_move(inode-1));
  var: ff_dump(.),
  fun:
    f_dump(inode) = -rd(inode)*(eta_speed(inode) - eta_speed(inode-1));
>;
```

The limiting states and transfers are associated with the states or transfers with index `inode+1` or `inode-1` appearing in node cell and transfer equations (`inode-1` for down limiting conditions and `inode+1` for up limiting conditions) in their order of appearance. In our example, in the `eta_speed` state node equation `ff_spring(inode+1)` appears before `ff_dump(inode+1)` and is therefore associated with `ff_dummy_1` while `ff_dump(inode+1)` is associated with the `ff_dummy_2` limiting transfer, as `ff_dummy_1` appears before `ff_dummy_2` in the limiting up transfers definitions. Verification of the grid index coherence should be eased with the following help printed in the listing header:

```

----- Informing on Dwn Eta definition -----
Var-name,          Function-name, index in eta vector
      eta_pos_wall      deta_pos_wall  1 [
      eta_speed_wall    deta_speed_wall 2 [

----- Informing on Eta Nodes definition -----
Var-name,          Function, k2index of (inode: 0 [ 1,...n_node ] n_node+1)
      eta_move          deta_move      1 [  3 ...  7 ]  9
      eta_speed         deta_speed     2 [  4 ...  8 ] 10

----- Informing on Up Phi definition -----
Var-name,          Function-name, index in ff vector
      ff_dummy_1        f_dummy_1 ]   7
      ff_dummy_2        f_dummy_2 ]   8
      ff_move_sum       f_move_sum ]   9
      ff_speed_sum      f_speed_sum ]  10
-----

----- Informing on Phi Nodes definition -----
Var-name,          Function, k2index of (inode: 0 [ 1,...m_node ] m_node+1)
      ff_spring         f_spring      -1 [  1 ...  5 ]  7
      ff_dump           f_dump        0 [  2 ...  6 ]  8
-----

```

All variable names and functions are free but has to be different. Any particular node-attached variable k is referred to as: '(inode:k)', where k has to be a Fortran expression allowed in arguments. The symbol 'inode' is reserved. As usual other Fortran instructions can be written within the Mortran block '< >' of each `set_` block.

Grid functions facility

Using 1D gridded models usually needs some space integral functions. For instance, spatial averaging would require writing an explicit sum of n-nodes variables. Such a function would generate tremendous space to give the derivatives, making Mortran buffer to overflow while being very inefficient.

To show the elegant way, two functions are provided, `avrg_node` and `vari_node` that computes space averaging or variance of a grid variable.

To compute the spatial average value of a transfer-variable name 'util2'

```
var: util_moy, fun: avrg_phi(12,util2(inode:1));
```

that is, 12 as first argument for 12 nodes, and first variable in the list. Of course, this function is recognized in the derivation rules and a Fortran entry point named `davrg_node` give the derivatives w.r.t. `eta(.)` and `ff(.)`.

For averaging an `eta(inode)` variable, use `fun: avrg_eta(12,temp(inode:1))`.

To compute the spatial variance of a transfer-variable name 'util2'

```
var: util_moy, fun: vari_phi(12,util2(inode:1));
```

The entry point for derivatives is `dvari_node`.

Both functions are decoded the same way: first, `vari_phi` is transformed in

```
...   avrg_node(12,util2(inode:1),j,ff(1),m_mult);
```

Now, the `avrg_node` Fortran function (see `mathlib`) has all the needed information to have corresponding index in `ff(.)` array of the first variable in the list, as well as the increment to jump from node to node.

The derivation rules in `$derive_mac` links to the entry point `dvari_node` with same arguments, where j takes the value of the differentiating variable `ff(j)`. The derivative will be zero if j is not among the components of the variable in the array `ff(.)` (see fortran code).

The same functions with a product-type argument are also available:

```
any = avrg_poids(12,Eta:densite(inode:1),Phi:util2(inode:1));
!           ---           ---
any = avrg_poids(12,Phi:util2(inode:1),Eta:densite(inode:1));
any = avrg_poids(12,Phi:util2(inode:1),Phi:util2(inode:1));
any = avrg_poids(12,Eta:densite(inode:1),Eta:densite(inode:1));
;
j=56; "chosen as to correspond to an index of ff(.) <-> util2(inode:2)"
any = F_D(avrg_poids(12,Phi:util2(inode:1),Phi:util2(inode:1)))/ff(j));
;
i=13;
any = F_D(avrg_poids(12,Eta:densite(inode:1),Eta:densite(inode:1)))/eta(i);■
```

for spatial averaging, and~:

```
any = vari_poids(12,Eta:densite(inode:1),Phi:util2(inode:1));
any = vari_poids(12,Phi:util2(inode:1),Phi:util2(inode:1));
any = vari_poids(12,Eta:densite(inode:1),Eta:densite(inode:1));
;
j=56;
any = F_D(vari_poids(12,Phi:util2(inode:1),Phi:util2(inode:1)))/ff(j));
;
i=13;
any = F_D(vari_poids(12,Eta:densite(inode:1),Eta:densite(inode:1)))/eta(i);■
```

for weighted variance. \bf care must be taken on giving the variable type `Eta` or `Phi` because no error diagnostic is made.

3.4 Double precision

The default for real variables is the `real` Fortran type. It is possible to use double precision instead. In that case all the occurrences of ‘`real`’ in mortran code is substituted with ‘`double precision`’ at precompilation stage, and the Lapack subroutine names are replaced by the double precision names. Eventual users’ declaration of `complex` Fortran variables is also changed to `double complex`.

This feature is turned on by `sel double` in ‘`selseq.kumac`’ with `cmz` and `double = 1` in the ‘`Makefile`’ with `make`.

In order for the model to run as well in double as in simple precision, some care should be taken to use the generic intrinsic functions, like `sin` and not `dsin`. No numerical constant should be passed directly to subroutines or functions, but instead a variable with the right

type should be used to hold the constant value, taking advantage of the implicit casts to the variable type.

3.5 Partial Derivatives

The partial derivative rules are included in a `Mortran` macro series in ‘`Derive_mac`’ of `Mini_ker` files. When using an unusual function, one should verify that the corresponding rules are in that file. It is easy to understand and add new rules in analogy with the already existing ones.

For instance, suppose one wants to use the intrinsic Fortran function `abs()`. Its derivatives uses the other function `sign()` this way:

```
&'(ABS(#))(/#)' = '(#1)(/#2)*SIGN(1.,#1)'
```

In such cases when one is adding a new rule, it is important to use the generic function names only (i.e. `sin` not `dsin`), because when compiling `Mini_ker` in the double precision version, or complex version, the generic names will correctly handle the different variable types - which is not the case when coding with specific function names.

3.5.1 Derivating a power function

Partial derivative of a function in exponent is not secure in its Fortran form `g(x,y)**(f(y))`. It should be replaced by `power(g,f)` of the `Mini_ker` ‘`mathlib`’, or by the explicit form `exp(f(y)*log(g(x,y)))`.

Its derivative will have the following form:

$$\begin{aligned}\partial_x f^g &= g f^{g-1} \partial_x f + f^g \log f \partial_x g \\ &= f^{g-1} (g \partial_x f + f \partial_x g)\end{aligned}$$

and is in the macros list already defined in: ‘`DERIVE_MAC`’.

3.6 Rules for programming non continuous models

Some models may originally be non continuous, as the ones using a Fortran instruction `IF`. Some may implicitly use a step function on a variable. In such cases, the model has to be set in a derivable form, and use of a “smooth step” offers an elegant solution.

One should be aware of that this apparently mathematical treatment currently indeed leads to a physical question about the macroscopic form of a physical law. At a macroscopic level, a step function is usually a nonsense. Taking the example of phase-change, a fluid volume does not change phase at once, and a “smooth change of state” is a correct macroscopic model.

`Mini_ker` provides with the smooth step function *Heavyside*¹ in the `Mini_ker` ‘`mathlib`’:

```
Delta = -1."K";
A_Ice = heavyside("in:" (T_K-Tf), Delta, "out:" dAIce_dT);
```

in this example, `Tf` is the ice fusion-temperature, `A_ice` gives the ice-fraction of the mesh-volume of water at temperature `T_k`. The smooth-step function is set close to the

¹ This naming is a joke for “Inert” Heaviside function.

hyperbolic tangent function of x/Δ , normalised from 0 to 1, with a maximum slope of 2.5, see figure Figure 3.1. Hence, this first step-function is anti-symmetric about zero.

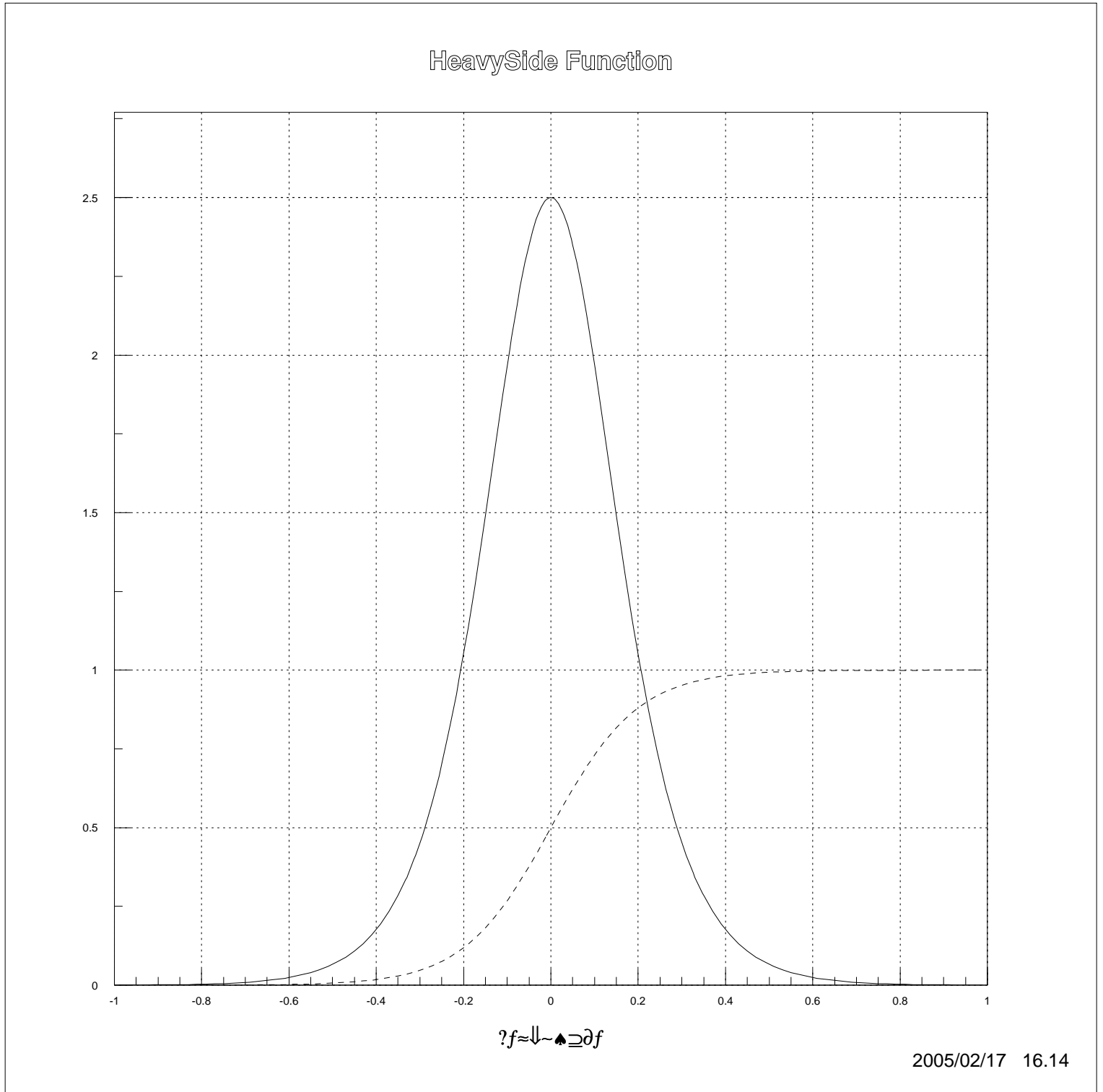


Figure 3.1: Heaviside function and derivative

For `Mortran` to be able to symbolically compute the partial derivatives, the rule is set in the table of macros as:

```
&'(HEAVYSIDE(##,##))(/#)' = '((#1)(/#4)*HEAVYDELTA(#1,#2,#3))'
```

which uses the Fortran entry point `HeavyDelta` in the Fortran function `heavyside`.

Another type of problem arises when coding a `var=min(f(x),g(x))` Fortran instruction. In such a case one does not want a derivative and one will code:

```
var = HeavySide(f(x)-g(x),Delta,dum)*g(x)
      + (1.-HeavySide(f(x)-g(x),Delta,dum)*f(x);█
```

or equivalently:

```
var = HeavySide(f(x)-g(x),Delta,dum)*g(x)
      + HeavySide(g(x)-f(x),-Delta,dum)*f(x);█
```

Warning: the value of the argument *Delta* is important because it will fix the maximum slope of the function that will appear as a coefficient in the Jacobian matrices. Moreover – and this is a very general statement concerning arguments in Fortran functions – NEVER enter a numerical value as argument, e.g. `heavyside(x,0.1)`, because it will not inherit of the contextual precision set for instance by `implicit double precision`: errors guaranteed!

Mini_ker also provides with another smooth step function that steps up from zero to one *oStepin* also in the Mini_ker `'mathlib'`:

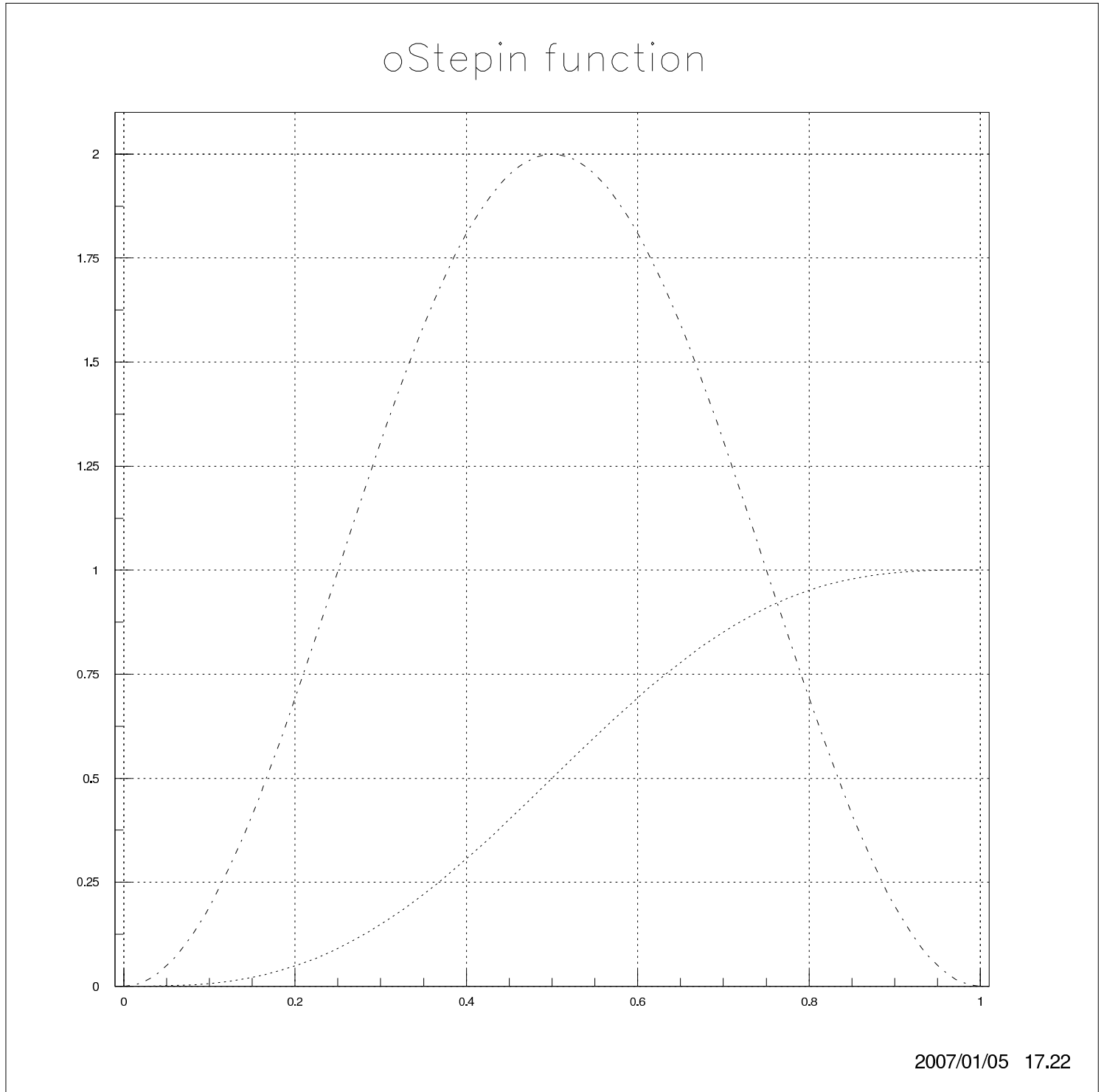


Figure 3.2: Step function and derivative

Unlike `Heavyside`, this step is asymmetric. The derivation rule calls for `oDeltin` function which is an entry point of `oStepin`.

3.7 Parameters

It is possible to specify some Fortran variables as specific model parameters. Model parameters may be used in sensitivity studies (see Section 4.1.1 [Sensitivity to a parameter], page 31) and in the adjoint model (see Section 4.2.4 [Sensitivity of cost function to parameters], page 35). Nothing special is done with parameters with Kalman filtering.

To specify parameters, first the number of such parameters has to be declared in ‘`dimetaphi`’ with the parameter `lp`. Then, if there are two parameters, they are first declared with

```
parameter (lp=2);
```

The parameters are fortran variables that should be initialized somewhere in ‘`zinit`’. For a variable to be considered as a parameter, it should be passed as an argument to the `Free_parameters` macro. For example if `apar` and `cpar` (from the predator example) are to be considered as parameters, `Free_parameters` should be called with:

```
Free_parameter: apar, cpar;
```

Forward sensitivities are explained later (see Section 4.1.1 [Sensitivity to a parameter], page 31), the syntax only is described here.

When used with `grid1d` models (see Section 3.3 [Describing 1D gridded model], page 17) the `inode` number may appear in parenthesis:

```
Free_parameter: rd(1), rk(2);
```

3.8 Observations and data

Some support for observations and interactions with data is available. The observations are functions of the model variables. They don’t have any action on the model result, but they may (in theory) be observed and measured. The natural use of these observations is to be compared with data that correspond with the values from real measurements. They are used in the Kalman filter (see Section 4.3 [Kalman filter], page 35).

The (model) observation vector is noted ω in this section (μ elsewhere, and the observation function is noted h):

$$\omega = h(\eta, \varphi)$$

3.8.1 Observations

The size of the observation vector is set in the ‘`dimetaphi`’ sequence by the `mobs` parameter. For example if there is one observation:

```
parameter (mobs=1);
```

The observation functions are set by a `set_probe<` macro in the ‘`zinit`’ sequence.

eqn: $Obs_tef(i) = f(eta(.),ff(.))$ [Macro]

This macro defines the observation equation as usual in a `set_block<`. `f` is a fortran expression which may be function of cell state variables, ‘`eta(1)`’...‘`eta(np)`’ and transfers ‘`ff(1)`’...‘`ff(mp)`’, or of course their symbolic names.

For example suppose that, in the predator-prey model, we only have access to the total population of preys and predators, we would have:

```
set_probe
< eqn: Obs_tef(1) = eta(1) + eta(2);
>;
```

The corresponding code is used with `sel obs` in `'selseq.kumac'` with `cmz` and `mobs = 1` in `'Makefile'` with `make`. And the feature is turned on and off at run time with the logical flag `zobs` corresponding to an available data from measurement

The observation vector is called `ff(mp+.)`, and is output in the file `'obs.data'`.

At each time step the derivative of the observation function with respect to transfer and cells variables are recomputed. The elimination of transfers is also performed to get the partial derivative of the observation function of the equivalent model, with states only, with respect to the states. In other words, the Kalman filter does not follow the TEF formalism, because the advance of the var-covar matrix could not yet be set in the TEF form.

The matrix are:

```
obead(.,.)
    derivative of observation function with respect to transfers.

obphid(.,.)
    derivative of observation function with respect to cell variables.

obspha(.,.)
    derivative of observation function in state space with respect to cell variables.
```

3.8.2 Data

The convention for data is that whenever some data are available, the logical variable `zgetobs` should be set to `'true.'`. And the `vobs(.)` vector should be filled with the data values. This vector has the same dimension than the observation vector and each coordinate is meant to correspond with one coordinate of the observation vector.

This feature is turned on by setting the logical variable `zdata` to `'true.'`, and the `zgetobs` flag is typically set in the `'zsteer'` sequence (see Section 2.5.1 [Executing code at the end of each time step], page 13). Every instnt data are available (`zgetobs` is true) the observations are written to the file `'data.data'`. With the Kalman filter more informations are output to the `'data.data'` file, see Section 4.3.2.2 [Kalman filter results], page 37.

3.9 Programming with cmz directives

3.9.1 Cmz directives used with mini_ker

The main feature of `cmz` directive is to use code conditionnaly for a given select flag. For example when the double precision is selected (see Section 3.4 [Double precision], page 22) the use of the conditionnal `double` flag may be required in case there is a different subroutine name for different types. If, for example, the user use the subroutine `smysub` for simple precision and `dmysub` for double precision the following code is an example of what could appear in the user code:

```
+IF,double
```

```

    call dmysub(eta);
+ELSE
    call smysub(eta);
+ENDIF

```

For a complete reference on cmz directives see the appendix Appendix B [Cmz directives reference], page 51.

3.9.2 Using cmz directives in mini_ker

In cmz the KEEP and DECK have their cmz directives preprocessed as part of the source files extraction. And the +KEEP and +DECK directives are automatically set when creating the KEEP or DECK. With make, files with these directives has to be created within the files that are to be preprocessed by the cmz directives preprocessor.

To be processed by make, a file that contains cmz directives should have a file suffix corresponding with the language of the resulting file and with the normal file suffix of that language. More precisely 'cm' should be added before the normal file suffix and after the '.'. Therefore if the resulting file language is associated with a suffix '*.suf*', the file with cmz directives should have a '*.cmsuf*' suffix. The tradition is to have a different suffix for main files and include files. To add directories searched for *cmfiles* (files with cmz directives) they should be added to the CMFDIRS makefile variable, separated by ':'.

Rules for preprocessing of the files are defined in the file 'Makefile.miniker' for the file types described in table 3.2:

language	file type	cmfile suffix	suffix	language
fortran	main/deck	.cmf	.f	ftn
fortran preprocessed	main/deck	.cmF	.F	f77
fortran preprocessed	include/keep	.cminc	.inc	f77
mortran	main/deck	.cmmtn	.mtn	mtn
mortran	include/keep	.cmmti	.mti	mtn

table 3.2: Association between file language, file type, file suffixes and language identifier in cmz directives. A main file is called a *deck* in cmz and an include file is called a *keep*.

4 Dynamic analysis of systems in mini_ker

4.1 Automatic sensitivity computation

An obvious advantage of having access to the Jacobian matrices along the system trajectory concerns automatic sensitivity analyses, as either:

- the sensitivity of all variables to perturbation in the initial condition of one state variable;
- the same sensitivities to an initial pulse (or step) on a transfer;
- the same sensitivities to a series of pulses (or steps) on a transfer;
- the same for a change in a parameter, eventually during the run;
- the sensitivity of the matrix of advance in state space to a change in a parameter.

This is declared in Zinit as:

```
! -----
! Sensitivities
! -----
Sensy_to_var
< var: eta_pray, pert: INIT;
  var: eta_pred, pert: INIT;
>;
```

Each variable at origin of a perturbation is declared as `var:`, and the type of perturbation in `pert:`. Here, INIT conditions are only allowed because the two variables are states variables. For transfers, `pert: pulse` corresponds to an initial pulse, `pert: step_resp` and `pert: step_eff` to initial steps, the difference between `_resp` (response form) and `_eff` (effect form) concerns the diagonal only of the sensitivity matrix (see Feedback gains in non-linear models).

Non initial perturbation can also be asked for:

```
Sensy_to_var
<
!*   var: eta_courant_L, pert: init at 100;
!*   var: ff_T_czcx,    pert: pulse at 100 every 20;
!*   var: ff_Psi_Tczcx, pert: step_eff;
!*   var: ff_Psi_Tczcx, pert: step_Resp at 10 every 100;
! *** premiers tests identiques a lorhcl.ref
    var: ff_courant_L , pert: step_eff;
    var: ff_T_czcx    , pert: step_eff;
    var: ff_Psi_Tczcx , pert: step_eff;
    var: ff_Psi_Tsz   , pert: pulse at 100 every 50;
>;
```

In this example taken from 'lorhcl', a sensitivity can increase so as to trespass the Fortran capacity, so that each sensitivity vector (matrix column) can be reset at some time-increment at III every JJJ;

It is noteworthy that these sensitivity analyses are not based on difference between two runs with different initial states or parameter values, but on the formal derivatives of the

model. This method is not only numerically robust, but is also rigorously founded as based on the TLS of the model¹.

If the `dimetaphi` sequence is built by the users, he should declare the number of perturbing variables as `nxp=`:

```
parameter (nxp=np,nyp=0,nzp=0);
```

here, all state variables are considered as perturbing variables.

The sensitivity vectors are output in the result files '`sens.data`' for cells and '`sigma.data`' for transfers. In those files the first column corresponds again with time, and the other columns are relative sensitivities of the cell states (in '`sens.data`') and transfers (in '`sigma.data`') with respect to the initial value of the perturbed state.

In our predator-prey example, the second column of '`sens.data`' will contain the derivative of $\eta_1(t)$ with respect to $\eta_1(t=0)$. Drawing the second column of '`sens.data`' against the first one gives the time evolution of the sensitivity of `eta-pred` to a change in the initial value of `eta-pray`. One can check in that it is set to 1 at $t=0$:

```
# Sensy_to: eta_pray      3      eta_pred      5
# time \ \ of: eta_pray   eta_pred   eta_pray   eta_pred
0.00000E+00 1.00000E+00 0.00000E+00 0.00000E+00 1.00000E+00
1.00000E-02 9.90868E-01 1.11905E-02 -1.26414E-02 9.98859E-01
```

The two last columns are the state sensitivity to a change in initial conditions of the number of predators.

In the same way, the $j+1$ th column of '`sigma.data`' will be the derivative of $\phi_j(t)$ with respect to $\eta_i(t=0)$. Here:

```
# Sensy_to: eta_pray      eta_pred
# time \ \ of: ff_interact ff_interact
0.00000E+00 1.60683E+00 8.47076E-01
1.00000E-02 1.59980E+00 8.18164E-01
```

the unique transfer variable gives rise to two sensitivity columns.

Sensitivity studies are usefull to assess the predictability properties of the corresponding system.

4.1.1 Sensitivity to a parameter

A forward sensitivity to a parameter will be computed when specified as described in Section 3.7 [Parameters], page 27. For example, suppose that the sensitivity to an initial change in the `apar` parameter of the predator model is of interest. In that case the number of parameters should be set to 1 in '`dimetaphi`':

```
parameter (lp=2);
```

The sensitivity calculs is turned on as a forward parameter specified on the `Free_parameter` list:

```
Free_parameter: [fwd: apar, cpar];
```

The result are in '`sensp.data`' for cells and '`sigmap.data`' for transfers.

¹ For a short introduction to automatic sensitivity analysis, see the document: <http://lmd.jussieu.fr/zoom/doc/sensibilite.ps>, in French, or ask for the more complete research document to a member of the TEF-ZOOM collaboration

```

# Sensy_to: pi_prandtl      3          4          pi_rayleigh_      6
# time \\ of: eta_courant_ eta_T_czcx  eta_T_sz      eta_courant_ eta_T
0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.000
2.00000E-03 -4.77172E-03 -3.99170E-05 3.55971E-05 -9.94770E-05 -1.004

```

In the above example from 'lorhc1' sensitivity of the three states with respect to an initial change in two parameters are independantly given (first line also numbers the column to easy gnuplot using).

4.1.2 Advance matrix sensitivity

It is possible to look at the sensitivity of the matrix of advance in states space (the matrix `aspha`) with regard to a parameter. The parameter must be accounted for in the parameter number and be in the parameter list, flagged as the matrix `mx` parameter, like in

```
Free_parameter: [mx: apar], cpar;
```

This feature is associated with a selecting flag, 'dPi_aspha'. One gets the result in the matrix `d_pi_aspha(.,.)` of dimension `(np,np)`.

This matrix may be used to compute other quantities, for example it may be used to compute the sensitivity of the eigenvalues of the state-advance matrix with regard to the `[fwd]` parameter. These additional computations have to be programmed by the user in 'zsteer' with matrices declared and initialized in 'zinit'. An example is given in the example 'lorhc1' provided with the Mini-Ker installation files, following a method proposed by Stephane Blanco.

4.2 Adjoint model and optimisation with mini_ker

In the following a possible use of mini_ker for optimisation is discussed. More precisely the use of adjoint and control laws in mini_ker are presented. Optimisation isn't the only application of these tools, but it is the most common one. In that case the adjoint may be used to determine the gradient of a functional to perturbations in the control laws, and an optimisation process can use this information to search for the optimum. Another application of the adjoint is to compute the sensitivity of a cost function to parameters (the ones declared in the `free_parameters:` list. Note that the cost function can be sensitive to probe's variables, even if these are uncoupled with standard variables in the forward calculations; this is the case when minimizing a quadratic distance function between probes (from the model) and the corresponding measurements.

The code is close transcription of the mathematical calculus described in <http://www.lmd.jussieu.fr/ZOOM/doc/Adjoint.pdf>. It essentially reverse time and transpose the four Jacobian matrices: states and transfers are saved in array dimensionned with `maxstep` Fortran parameter.

4.2.1 Overview of optimisation with mini_ker

In the proposed method, mini_ker is run twice, one time forward and then backward to determine the trajectory and the adjoint model. After that the control laws are modified by a program external to mini_ker. The same steps are repeated until convergence. More pecisely,

forward The command law $h(t)$ is given (by an explicit law or taken from a file). The trajectory is computed in a classical way, with the additionnal computation of

the functional to be optimised, J , prescribed with specific `f_set` macros. The states, transfers and control laws are stored.

backward The adjoint variable is computed from the last time T backward. The time increment is re-read as it could have changed during the forward simulation. The system is solved by using the same technics as in the forward simulation, but with a negative time step.

external phase

Now the command should be corrected. This step isn't covered here, but, for example, minuit the optimisation tool from the CERN could be used. In order to ease such a use of mini_ker, the principal program has to be compiled as a subroutine to be driven by an external program (see Section 3.2 [Calling the model code], page 15).

The functionnal J to be optimised is defined as

$$J = \psi[\eta(T), \varphi(T), h(T)] + \int_0^T l[\eta(\tau), \varphi(\tau), h(\tau)] d\tau$$

Where ψ is the final cost function, l is the integrand cost function and h represents the control laws variations.

The general use of the adjoint model of a system is the determination of the gradient of this J functional to be optimised, with respect to perturbations of the original conditions of the reference trajectory, that is, along its GTLS².

4.2.2 Control laws

Each control law is associated with one cell or transfer equation, meaning that a command associated with an equation does not appear in any other equation. It is still possible to add commands acting anywhere by defining a transfer equal to that command.

The control laws associated with states are in the `ux_com(.)` array, control laws associated with transfers are in the `uy_com(.)` array. The control laws may be prescribed even when there is no adjoint computed, nor any optimisation, and they are used during simulation, in which case they will act as external sources. To enable the use of commands, the logical flag `Zcommand` should be `.true..`

The command can be given either as:

1. a table of numerical values in the files `'uxcom.data'` and `'uycom.data'`.
2. a function of the problem variables. To turn that feature on the logical flag `Zlaw` should be set to `.true.` in `'zinit'`. The sequence `'zcmd_law'` should hold the code filling the `ux_com(.)` and `uy_com(.)` arrays, as the code from that sequence is used whenever the control laws are needed. In that case the files `'uxcom.data'` and `'uycom.data'` will be filled by the command values generated by the function along the trajectory.

For example in the Lotka-Volterra model, the parameter `apar` could be a control variable. In that case, `apar` would be defined as the variable `ux_com(1)`, and either entered as a law in the sequence `'zcmd_law'`, either written in the file `'uxcom.data'` step by step. In that

² General Tangent Linear System, i.e. the TLS circulating along a trajectory. See the explanation in the document <http://www.lmd.jussieu.fr/Zoom/doc/Adjoint.pdf> (in French).

case, there must be a perfect correspondance between time of the commands and time of the run.

4.2.3 Cost function coding and adjoint modeling

First of all the flag `zback` should be set to `.true.` in order to allow adjoint model computation:

```
Zback=.true.;
```

The two functions `cout_Psi` corresponding with the final cost and `cout_l` corresponding with the integrand cost are set up with the `f_set` macros.

```
f_set cout_Psi = f(eta(.),ff(.),ux_com(.),uy_com(.)) [Macro]
```

This macro defines the final cost function. `f` is a fortran expression which may be function of cell state variables, `'eta(1)'`...`'eta(np)'`, transfers `'ff(1)'`...`'ff(mp)'`, state control laws `'ux_com(1)'`...`'ux_com(np)'`, and transfer control laws `'uy_com(1)'`...`'uy_com(mp)'`.

```
f_set cout_l = f(eta(.),ff(.),ux_com(.),uy_com(.)) [Macro]
```

This macro defines the integrand cost function. `f` is a fortran expression which may be function of cell state variables, `'eta(1)'`...`'eta(np)'`, transfers `'ff(1)'`...`'ff(mp)'`, state control laws `'ux_com(1)'`...`'ux_com(np)'`, and transfer control laws `'uy_com(1)'`...`'uy_com(mp)'`.

For example, the following code sets a cost function for the masselottes model:

```
! Initialisation
  F_set cout_Psi = eta_move(inode:1);
!and f_set cout_l integrand in the fonctionnal
  F_set cout_l = 0.;
```

In that example the functional is reduced to the final value of the first state component. Here, the adjoint vector will correspond to the final sensitivity (at $t = 0$) of that component (here the first masselotte position) to a perturbation in all initial conditions³.

The following variables are set during the backward phase, and output in the associated files:

var	file	explanation
<code>v_adj(.)</code>	<code>'vadj.data'</code>	adjoint to <code>eta(.)</code>
<code>w_adj(.)</code>	<code>'wadj.data'</code>	adjoint to <code>ff(.)</code>
<code>wadj(mp+.)</code>	<code>'gradmuj.data'</code>	adjoint to <code>ff(mp+.)</code>
<code>graduej(.)</code>	<code>'gradxj.data'</code>	adjoint to <code>ux_com(.)</code>
<code>gradufj(.)</code>	<code>'gradyj.data'</code>	adjoint to <code>uy_com(.)</code>
<code>hamilton</code>	<code>'hamilton.data'</code>	time increment, hamiltonian, cost function increment

³ For detailed explanation of the adjoint model, see the document in pdf (<http://www.lmd.jussieu.fr/ZOOM/doc/Adjoint.pdf>) or .ps.gz (<http://www.lmd.jussieu.fr/ZOOM/doc/Adjoint.pdf>)

4.2.4 Sensitivity of cost function to parameters

The sensitivity of the cost function to all the parameters given as arguments of `Free_parameters` is computed. For the predator model the sensitivity of a cost function consisting in the integral of the predator population with respect with `apar` an `cpar` is obtained with a number of parameters set to 2 in `'dimetaphi'`:

```
parameter (lp=2);
```

And the cost function and `Free_parameters` list in `'zinit'`:

```
f_set cout_Psi = eta(2);
f_set cout_l = eta(2);
Free_parameters: apar,cpar;
```

`apar` and `cpar` also have to be given a value. The result is output in `'gradpj.data'`.

4.3 Kalman filter

The Kalman filter allows for data assimilation along the model run. In that case it is assumed that there is a real-world model with stochastic perturbations on the states, and that noisy observations are available. The situation implemented in `Mini_Ker` corresponds to a continuous stochastic perturbation on the state, and discrete noisy observations. In the TEF this leads to:

$$\begin{aligned}\partial_t \eta(t) &= g(\eta(t), \varphi(t)) + W(t)\mu \\ \varphi(t) &= f(\eta(t), \varphi(t)) \\ \omega(t) &= h(\eta(t), \varphi(t)) + \nu\end{aligned}$$

(notice that in this paragraph, ω stands for the probe vector μ elsewhere, and μ is here a noise source.

The observations ω are available at discrete time steps $t = s_i$. The stochastic perturbation on state, μ is characterized by a variance-covariance matrix Q and the noise on the observation, ν has a variance-covariance matrix R . W relates states with stochastic perturbations. At each time step the Kalman filter recomputes an estimation of the state and the variance-covariance matrix of the state.

In the following we use the example of a linear model with perturbation on state and observation of state. The model has 3 states and 3 corresponding transfers (equal to the states), but the error on the state is of dimension 2. The 3 states are observed. The corresponding equations read:

$$\begin{cases} \partial_t \eta_1 = a_{11}\eta_1 + a_{12}\varphi_2 + a_{13}\varphi_3 + W_{11}\mu_1 + W_{12}\mu_2 \\ \partial_t \eta_2 = a_{21}\varphi_1 + a_{22}\eta_2 + a_{23}\varphi_3 + W_{21}\mu_1 + W_{22}\mu_2 \\ \partial_t \eta_3 = a_{31}\varphi_1 + a_{32}\varphi_2 + a_{33}\eta_3 + W_{31}\mu_1 + W_{32}\mu_2 \end{cases}$$

$$\begin{cases} \varphi_1 = \eta_1 \\ \varphi_2 = \eta_2 \\ \varphi_3 = \eta_3 \end{cases}$$

$$\begin{cases} \omega_1 = \varphi_1 + \nu_1 \\ \omega_2 = \eta_2 + \nu_2 \\ \omega_3 = \eta_3 + \nu_3 \end{cases}$$

4.3.1 Coding the Kalman filter

First of all the Kalman filter code should be activated. The observations code is also required (see Section 3.8.1 [Observations], page 27). If `cmz` is used the code should be selected with the select flags `kalman` and `obs` in the `'selseq.kumac'`:

```
sel kalman
sel obs
```

With make the `kalman` variable should be set to 1, this will also trigger the selection of the observations:

```
kalman = 1
```

The `kalman` code is actually used by setting the flag `zkalman` to `.true.`, for example in the `'zinit'`:

```
zkalman = .True.;
```

This will set the `zobs` and `zdata` flags to `.true.` (see Section 3.8 [Observations and data], page 27).

With the Kalman filter the dimension of estimated states, of the error on the state and of the observation, the W matrix, the observation function, the initial variance-covariance matrices on the state and the variance-covariance matrices of errors have to be given.

4.3.1.1 Kalman filter vectors dimensions

These dimensions should be set in the `'dimetaphi'` sequence. The size of the estimated states is given by the parameter `nkp`. You can set this to `np` if all the states are estimated, but in case there are some deterministic state variables, `nkp` may be less than `np`. In that case the first `nkp` elements of `eta(.)` will be estimated using the Kalman filter.

The error on state dimension is associated with the parameter `nerrp` and the size of the observations vector is `mobs` (see Section 3.8.1 [Observations], page 27). In our example the dimensions are set with:

```
parameter (nkp=np);
parameter (mobs=3);
parameter (nerrp=2);
```

All the states are estimated, there are three observation functions and the error on the state vector is of dimension 2.

4.3.1.2 Error and observation matrices

Initial variance-covariance matrix on the state

The variance-covariance on the state matrix is `covfor(.,.)`. The initial values have to be given for this matrix, as in our example:

```
covfor(1,1) = 1000.; covfor(1,2) = 10.; covfor(1,3) = 10.;
covfor(2,1) = 10.; covfor(2,2) = 5000.; covfor(2,3) = 5.;
covfor(3,1) = 10.; covfor(3,2) = 5.; covfor(3,3) = 2000.;
```

This matrix is updated by the filter at each time step because the states are pertubated by some noise, and when assimilation takes place as new information reduce the error.

Observations and error on state matrix

The matrix that relates errors on states vector components to states, corresponding with W is `mereta(.,.)`. In our example it is set by:

```
mereta(1,1) = 1.; mereta(1,2) = 0.;
mereta(2,1) = 0.; mereta(2,2) = 1.;
mereta(3,1) = 0.5; mereta(3,2) = 0.5;
```

The observation functions are set by a `f_set` macro with `Obs_tef(.)` as described in Section 3.8.1 [Observations], page 27. In our example the observation functions are set by:

```
f_set Obs_tef(1) = ff(1) ;
f_set Obs_tef(2) = eta(2);
f_set Obs_tef(3) = eta(3);
```

Error variance-covariance matrices

The variance-covariance matrix on observation noise is `covobs(.,.)` set, in our example, by:

```
covobs(1,1) = 0.3; covobs(1,2) = 0.; covobs(1,3) = 0.;
covobs(2,1) = 0.; covobs(2,2) = 0.1; covobs(2,3) = 0.;
covobs(3,1) = 0.; covobs(3,2) = 0.; covobs(3,3) = 0.2;
```

The variance-covariance matrix on state noise is `coveta(.,.)` set, in our example, by:

```
coveta(1,1) = 0.2; coveta(1,2) = 0.001;
coveta(2,1) = 0.001; coveta(2,2) = 0.1;
```

These matrices are not changed during the run of the model as part of the filtering process. They may be changed by the user in ‘`zsteer`’.

4.3.2 Kalman filter run and output

4.3.2.1 Feeding the observations to the model

The observations must be made available to the model during the run. These observations are set in the `vobs(.)` array, and the assimilation (also called the analysis step of the filter) takes place when the logical variable `zgetobs` is set to `.true.` (see Section 3.8.2 [Data], page 28).

These steps are typically performed in the ‘`zsteer`’ sequence. In this sequence there should be some code such that when there are data ready to be assimilated, `zgetobs` is set to `.true.` and the data is stored in `vobs(.)`, ready for the next step processing.

4.3.2.2 Kalman filter results

The estimated states and transfers are still in the same ‘`.data`’ files, ‘`res.data`’ and ‘`tr.data`’ and there is the additional file with observations, called ‘`obs.data`’ (see Section 3.8.1 [Observations], page 27). Each time `zgetobs` is `.true.` the data, and the optimally weighted innovations are output in the file associated with data, ‘`data.data`’ (see Section 3.8.2 [Data], page 28).

4.3.3 Executing code after the analysis

The analysis takes place before the time step advance when `zgetobs` is `.true.`. It may be usefull to add some code after the analysis and before the time step advance. For example

the analysis may lead to absurd values for some states or parameters, it could be useful to correct them in that case. The sequence included after the analysis is called 'kalsteer'. At this point, in addition to the usual variables the following variables could be useful:

```
etafor(.)
    The state before the analysis.

K-gain(.)
    The Kalman gain.

innobs(.)
    The innovation vector (observations coherent with the states minus data values).

covana(.,.)
    The variance-covariance error matrix after the analysis.
```

4.4 Feedback gain

The feedback dynamic gain associated with a feedback loop can be expressed as the inverse Borel transform of the coefficient of the reduced scalar coupling matrix, $g(\tau)$, associated with a transfer. A Borel sweep provides this $g(\tau)$. Therefore it is an interesting tool for the characterization of the feedback loop⁴.

As explained in the ZOOM web page document http://www.lmd.jussieu.fr/ZOOM/doc/Feedback_Gain.pdf, this allows for the calculation of the dynamic gain and factor of any feedback that goes through a unique transfer variable. An example of the conclusions that can be drawn from such an analysis is provided in the same document.

For linear systems – whose GTLS are autonomous along the whole trajectory – the τ function of the feedback gain is independent of the position on the system trajectory. But in general it is dependant, and one can analyse the function $g(\tau; t)$ defined on a segment t of the trajectory.

The document introducing the TEF-ZOOM technique explains how a Crank-Nicolson scheme for the time discretisation symbolically gives the solution of the Borel transform of the system. One can identify the dt variable with the Borel τ within a factor 2. Hence, to numerically study the τ dependency of the transform of various coefficients in the system coupling matrix at one point in time, one can calculate the Borel transform of the TLS solutions by making a time-step sweep.

The function $g(\tau; t)$ is simply output for the feedback gain attached to a unique $ff(k)$ transfer variable. All the relevant informations should be entered in the 'zinit' sequence.

4.4.1 Specifying the Borel sweep

First of all the logical flag `ZBorel` should be raised:

```
ZBorel=.true.;
```

The index of the studied transfer is given in the `index_ff_gain` variable

```
index_ff_gain=7;
```

⁴ More generally, the Borel sweep allows the numerical study of the dependency in τ of the Borel transform of various coefficients in the system coupling matrix.

At each time step a Borel sweep may be performed. The time steps of interest are specified with three variables, one for the first step, one for the last step and one for the number of steps between two Borel sweeps:

`istep_B_deb`
First time step for the Borel sweep.

`istep_B_fin`
Last time step for the Borel sweep.

`istep_B_inc`
Number of time steps between Borel sweeps.

In the following examples Borel sweeps are performed from the time step 1000 up to the time step 1200, with a sweep at each time step:

```
istep_B_deb=1000;
istep_B_fin=1200;
istep_B_inc=1;
```

For each Borel sweep, the range of the τ variable should be set. As this is a multiplicative variable the initial value, a multiplicative factor and the number of values are to be given.

`tau_B_ini`
Initial value for τ .

`tau_B_mult`
Multiplicative factor for sweep in *tau*.

`itau_max` Number of τ values.

For example, in the following, at each time step, the Borel transform will be computed for τ values starting at 0.2 and then multiplied a hundred times by $\sqrt{\sqrt{2}}$

```
tau_B_ini=0.2;
tau_B_mult=sqrt(sqrt(2.));
itau_max=100;
```

When the initial value of τ is set to a negative value (*i.e.* `tau_B_ini=-0.2;`), the Borel sweep will first be applied with `itau_max` negative values for `-0.2, tau_B_mult*(-0.2),...`, then for the zero value, and finally for the symmetric positive values, resulting in `2*itau_max+1` values for τ .

The whole example reads

```
! -----
! Feedback gain
! Borel
! -----
ZBorel=.true.;
if ZBorel
< istep_B_deb=1000;
   istep_B_fin=1200;
   istep_B_inc=1;
;
   index_ff_gain=7;
```

```

tau_B_ini=0.2;
tau_B_mult=sqrt(sqrt(2.));
itau_max=100;
z_pr/Borel/:tau_B_mult,tau_B_ini*(tau_B_mult)**itau_max;
>;

```

Instead of using the index of the transfer in `index_ff_gain` it is possible to specify the symbolic name of the transfer, whenever the symbolic model description is used (see Section 2.3 [Symbolic model description], page 8). In that case the transfer is specified by the `zborel` for macro. For example if the transfer selected for the feedback gain computation is `b_transfer`, it can be selected with:

```
zborel for: b_transfer;
```

4.4.2 Borel sweep results

The file `'tau_Borel.data'` gives the τ values of the *tau* sweep, and the file `'gains.data'` records the feedback gain function values of $g(\tau)$, with one line for each sweep along the trajectory. In the 1.01 version, a new feature is also provided giving the poles and residuals of the Borel transform in the file `'vpgains.data'`. Consult the subroutine `Boreleig` for (not definitive) output description.

One can easily obtain the surface contours of $g(t, \tau)$ using the Fortran program provided as `'gains.f'` and its compilation shell `'gains.xqt'`, that builds 2D histograms for PAW, in which one uses the `'borels.kumac'` provided `kumac`.

4.5 Stability analysis of fastest modes

The preceding analyses are done along with a simulation. One has also the possibility of using in a more classical fashion the state advance matrix A_{st} , after the end of the simulation. Code to perform the SVD (Singular Value Decomposition) of the state matrix A_{st} and also of $A_{st} + A_{st}^\dagger$ is provided with `mini_ker`. The singular elements of these two matrices correspond to the most rapid modes of instability of the perturbed system.

The Singular value decomposition of a matrix is noted

$$UwV^\dagger$$

An executable file, `'sltc.exe'` is generated and running this file will produce the corresponding results.

4.5.1 Singular Value Decomposition with cmz

The `cmz` macro `smod SLTC` prepares a main program (`'circul'` of `+PATCH SLTC`), provided as a base for user's own analysis, in the directory `'sltc/'`.

4.5.2 Singular Value Decomposition with make

To compile the singular value decomposition executable with `make` you can do

```
make sltc.exe
```

If you want to have a separate directory for the SVD, you should copy the sequence `'dimetaphi.inc'` (or make a link to that file) to the directory. You should also copy the file `'Makefile.sltc'` from the `'template/'` directory in this directory, rename it `'Makefile'` and

set the mini_ker directory path in the `miniker_dir` variable. For example, if the mini_ker directory is in `/u/src/mini_ker`:

```
miniker_dir = /u/src/mini_ker
```

4.5.3 Singular Value Decomposition run and output

As it is, the `sltc.exe` executable generated by the compilation determines the SVD. This program requires `title.tex` (see [Title file], page 7) to transmit a title for output and graphics, and `aspha.data` (see Section 2.4.3 [Running a simulation and using the output], page 11) to access the state matrix. To get access to these files (in case they are not in the current directory) it is possible to make a link to the corresponding files in the model directory. Once it is done the program may be run:

```
./sltc.exe
```

The files `u.data`, `w.data`, and `v.data` holds the singular elements for A_{st} (U , w and V), and `us.data`, `ws.data`, and `vs.data` holds the singular elements of $A_{st} + A_{st}^\dagger$. The corresponding macros `.kumac` for PAW⁵ are also generated.

4.6 Generalized linear tangent system analysis

The state matrix A_{st} may also be used to compute the GTLS propagator (or state transition matrix applied to perturbation), after the simulation. The algorithm is a finite product of 5th order development of $\Phi(t + \delta t, t) = \exp A_{st}\delta t$. Numerous element of analysis are given, in particular the determination of the Lyapunov exponents of the system.

An executable file, `sltcirc.exe` is generated and running this file will produce the corresponding results.

4.6.1 Generalized tangent linear system with cmz

The cmz macro smod SLTCIRC prepares a main program (`circule` of `+PATCH SLTCIRC`), in the directory `sltcirc/`.

4.6.2 Generalized tangent linear system with make

To compile the GTLS analysis executable with `make` you can do

```
make sltcirc.exe
```

If you want to have a separate directory for the GTLS analysis, you should copy the sequence `dimetaphi.inc` (or make a link to that file) to the directory. You should also copy the file `Makefile.sltcirc` from the `template/` directory in this directory and rename it `Makefile` and set the mini_ker directory path in the `miniker_dir` variable.

4.6.3 Generalized tangent linear system analysis run and output

The `sltcirc.exe` executable generated by the compilation computes the elements of analysis of the system. This program requires `title.tex` to transmit a title for output and graphics (see [Title file], page 7), `aspha.data` to access the state matrix and `dres.data`, because time-step can be changed along the simulation (see Section 2.4.3 [Running a simulation and using the output], page 11)⁶. To get access to these files (in case they are not in

⁵ Explanation in the research paper about SLTC (A11 2003) available on request.

⁶ cf our research texts about propagator analyses in SLTC, and “les Gains sur champs (A11 2003-2004)”

the current directory) it is possible to make a link to the corresponding files in the model directory. Once it is done the program may be run:

```
./sltcirc.exe
```

The following table gives the correspondence between variable name, result file and ntuple number, with a short explanation:

var	file	ntuple	explanation
<code>p(.,.)</code>	'phit.data'	55	propagator from 0 to t , $\Phi(t, 0)$
<code>up(.,.)</code>	'uphit.data'	50	Left singular vectors U in the SVD of Φ
<code>wp(.)</code>	'wphit.data'	51	singulat values w in the SVD of Φ
<code>vp(.,.)</code>	'vphit.data'	52	Right Singular Vectors V in the SVD of Φ
<code>wr(.)</code>	'wr.data'	53	real part of eigen values of $\Phi(t, 0)$
<code>wi(.)</code>	'wi.data'	54	imaginary part of eigen values of $\Phi(t, 0)$
<code>lwp(.)</code>	'lwphit.data'	67	Lyapunov exponents

5 Advanced use of mini_ker with make

5.1 Make variables

The ‘`Makefile.miniker`’ Makefile provided in the distribution should be included as it defines a lot of important variables and rules.

The following make variables can be set by the user:

`miniker_dir`

that variable should hold the mini_ker sources directory. If you installed mini_ker that variable should be set to ‘`$(includedir)/mini_ker`’. If you use the sources right from the sources directory it should be set to the sources package directory.

MTNDIRS This variable can hold a ‘:’ delimited list of directories that will be searched for mortran include files.

CMFDIRS This variable can hold a ‘:’ delimited list of directories that will be searched for cmz directive include files.

SEL This variable holds a ‘,’ delimited list of select flags, for example `monitor`, `gridid`, `debug`.

LDADD This variable can be used to add libraries flags and files. It is used in the default linking command/rule.

`miniker_user_objects`

This variable should hold a space separated list of additional object files to be linked with the model and helper object files.

CAR2TXTFLAGS

cmz directives preprocessor flag.

kalman This variable should be set to 1 if you want to use the kalman filter (see Section 4.3 [Kalman filter], page 35).

double This variable should be set to 1 if you want to have a double precision code (see Section 3.4 [Double precision], page 22).

obs This variable should be set to 1 if you want to have a handling of observations as described in Section 3.8.1 [Observations], page 27.

The following variables are already set and may be used (some are set by `./configure` see Section A.4.2 [Configuration], page 49):

`miniker_principal_objects`

The list of object files needed for the model build, together with some helper object files often used but not strictly required for the linking.

DEPDIR The name of a hidden directory containing the dependencies computed for the main mortran files.

F77

FC

FFLAGS

LDFLAGS Compiler and linker related variables set by `./configure`.

LIBS This variable should hold the link flags and files required to build `mini_ker`, set by `./configure`.

CAR2TXT

MORTRAN

MTNFLAGS

MTNDEPEND

 Preprocessor and preprocessor flags, set by `./configure`.

5.2 Rules

The following rules are defined in the `'Makefile.miniker'` file.

miniker-clean
 remove the fortran files generated from the mortran files. Remove the object files.

miniker-mtn-clean
 remove the mortran files generated from the files with `cmz` directives.

 Various rules to preprocess files with `cmz` directives and mortran files and to compile fortran files.

If the user needs a mortran main file, he may take advantage of the rule used to compute the dependencies of a mortran file. If the file is called, say, `'mtnfile.mtn'` leading to `'mtnfile.f'`, the following include should lead to the automatic creation, updating and inclusion of a file describing the dependencies of `'mtnfile.mtn'` in the `'Makefile'`:

```
include $(DEPDIR)/mtnfile.Pf
```

5.3 Linking rule

The rule used for the linking of the model file is not in the `'Makefile.miniker'` file but should be provided in the user `'Makefile'` for more flexibility. The default rule uses the variables `miniker_user_objects` for additional object files and `LDADD` for additional linking flags and files, those variables are there to be changed by the user.

The object files required by the `mini_ker` code are in the make variable `miniker_principal_objects`, this variable is also used. The value of the variables `FC` for the Fortran compiler, `FFLAGS` for the Fortran compiler flags and `LDFLAGS` for the linker flags should be set to right values; `LIBS` should also be right and hold the link flags and link files required to compile the `mini_ker` model. These variables are set by by `./configure` during configuration (see Section A.4.2 [Configuration], page 49) and used in the default rule:

```
$(model_file): $(miniker_user_objects) $(miniker_principal_objects)
               $(FC) $(FFLAGS) $(LDFLAGS) $~ $(LDADD) $(LIBS) -o $@
```

In case this isn't right it may be freely changed. You should certainly refer to the section "Top" in *GNU Make Manual* manual to understand what that rule exactly means and make your own.

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Appendix A Installation

A.1 Programming environments

Mini_ker is not a traditional software in that it isn't a library or an interpreter but rather a set of source and macro files that combine with the user model code and enable to build a binary program corresponding with the model. It requires a build environment with a preprocessor, a compiler and facilities that automate these steps.

Two different environments are proposed. One uses `cmz` (<http://wwwcmz.web.cern.ch/wwwcmz/index.html>), while the other is based on `make`. Other libraries are needed, the CERN Program Library (`cernlib`) and `lapack`.

A.2 Common requisites

Whatever method is used a Fortran 77 compiler is required. The compilers that have been used so far are `g77`, `gfortran` and the Sun Solaris compiler.

The CERN Program Library, available at <http://wwwasd.web.cern.ch/wwwasd/cernlib/>, has to be installed. On Windows, in case you want to use the compiler from the GNU compiler collection with `cygwin` or `MINGW/MSYS` you can use the binaries provided at <http://zyao.home.cern.ch/zyao/cernlib.html>. On Mac OS X, the `cernlib` provided by `fink` (package `cernlib-devel`) can be used.

You should also have `LAPACK`, available at <http://www.netlib.org/lapack/>. `LAPACK` can also be installed as part of the CERN Library or as part of the <http://math-atlas.sourceforge.net/> (`ATLAS`) implementation. On most Linux distributions a `lapack` package is available. On Mac OS X, the `ATLAS` implementation provided by `fink` or the frameworks from `Xcode` can be used.

A.3 Mini_ker with cmz

First of all you have to get the `cmz` file `'mini_ker.cmz'` and put it in a directory. In that same directory you should create a directory for each of your models. In the model directory you should copy the file `'selseq.kumac'` available with `mini_ker`, and create your own `cmz` file for your model, called for example `'mymodel.cmz'`. You should also have installed the `kumac` macro files handling Mortran compilation, the associated shell scripts and the `Mortran` preprocessor.

A.4 Mini_ker with make

A.4.1 Additional requirements for Mini_ker with make

The package has been tested with GNU `make` and Solaris `make`.

Suitable preprocessors should also be installed. Two preprocessors are required, one that preprocesses the `cmz` directives, and a `Mortran` preprocessor. A `cmz` directives processor written in `perl`, is distributed in the `car2txt` package available at http://www.environnement.ens.fr/perso/dumas/mini_ker/software.html. A `Mortran` package with a command able to preprocess a `Mortran` file given on the command line with a syntax similar with the `cpp` command line syntax is also required. Such a

mortran is available at http://www.environnement.ens.fr/perso/dumas/mini_ker/software.html.

A.4.2 Configuration

The package is available at http://www.environnement.ens.fr/perso/dumas/mini_ker/software.html. It is available as a compressed tar archive. On UNIX, with GNU `tar` it may be unpacked using

```
$ tar xzvf mini_ker-1.02b.tar.gz
```

The detection of the compiler, the preprocessors (`car2txt` and `mortran`), and the libraries are performed by the `configure` script. This script sets the appropriate variables in makefiles. It can be run with:

```
$ cd mini_ker-1.02b
$ ./configure
```

If the output of `./configure` doesn't show any error it means that all the components are here. It is possible to give `./configure` switches and also specify environment variables (see also `./configure --help`):

`--with-static-cernlib`

This command line switch forces a static linking with the `cernlib` (or a dynamic linking if set to `no`).

`--with-cernlib`

This command line switch can be used to specify the `cernlib` location (if not detected or you want to use a specific `cernlib`).

`--with-blas`

`--with-lapack`

With this command switch, you can specify the location of the `blas` and `lapack` libraries.

For example, on mac OS X this can be used to specify the `blas` and `lapack` from the Apple frameworks:

```
./configure \
--with-blas=/System/Library/Frameworks/vecLib.framework/versions/A/vecLib \
--with-lapack=/System/Library/Frameworks/vecLib.framework/versions/A/vecLib
```

`F77`

`FC`

`FFLAGS`

`LDFLAGS` Classical compiler, compiler flags and linker flags.

`MORTRAN` This environment variable holds the `mortran` preprocessor command (default is `mortran`).

`MTNFLAGS` This environment variable holds command line arguments for the `mortran` preprocessor. It is empty in the default case.

`MTN` This environment variable may be used to specify the `mortran` executable name and/or path, it should be used by the `mortran` command. (default is empty, which leads to a `mortran` executable called `mtn`).

MTNDEPEND

This environment variable may be used to specify the mortran dependencies checker executable. It should be used by the `mortran` command. (default is empty, which leads to a mortran dependencies checker called `mtndepend`).

After a proper configuration, if `make` is run then the example models should be build. You have to perform the configuration only once.

A.4.3 Installation with make

Mini_ker can be installed by running

```
make install
```

It should copy the sources and the `'Makefile.miniker'` file in a `'mini_ker'` directory in the `$(includedir)` directory, and copy the templates in `'$(datadir)/mini_ker'`. The default for `$(includedir)` is `'/usr/local/include'` and the default for `$(datadir)` is `'/usr/local/share'`, these defaults may be changed by `./configure` switches `'--prefix'`, `'--includedir'` and `'--datadir'`. See `./configure --help` and the `'INSTALL'` file for more informations. The helper script `'start_miniker'` should also be installed.

The installation is not required to use comfortably `mini_ker`. Indeed the only thing that changes with the sources and the `'Makefile.miniker'` directory location is the `miniker_dir` variable in a project `Makefile`.

Appendix B Cmz directives reference

The cmz directives are described together with the other features of cmz in the cmz manual at <http://wwwcmz.web.cern.ch/wwwcmz/>, the important ones are nevertheless recalled here, especially for those that use make and don't need the whole features of cmz.

After the description of the generic features, we turn to the cmz directive of interest. There are three kinds of cmz directives that are of use within `mini.ker`: one kind that introduce files, the other for conditionnal compilation and the third for sequence inclusion.

B.1 Cmz directives general syntax

The cmz directives always begin with a '+' in the first column, optionnaly followed by any number of '_' that may be used for indentation, then the directive label, case insensitive, followed by the directive arguments separated by ','. The arguments are also case insensitive. Optional spaces may be around directive arguments. An optionnal '.' ends the directive arguments and begin a comment, everything that follows that '.' is ignored.

B.2 Conditional expressions

A directive argument common to all the directives is the conditionnal expression. A conditionnal expression may be true or false, it is a combination of select flags. the select flags are combined with logical operators. A select flag itself is true if it was selected. A select flag *selflag* is selected by using the `sel selflag` instruction in cmz. It is selected by passing the `-D selflag` command line switch to the call of the cmz directives preprocessor when using make.

A '-' negates the expression that follows. Parenthesis '(' and ')' are used for the grouping of subexpressions. '|' and ',' are for the boolean or: an expression with a or is true if the expression on the left or the expression on the right of the or is true. '&' is for the boolean and: an expression with an and is true if the expression on the left and the expression on the right are true.

The grouping is left to right when there is no parenthesis, with or and '&' having the same precedence. Therefore

```

a&b|c    ≡    (a&b)|c
a|b&c    ≡    (a|b)&c
a|b&c  is not  a|(b&c)
a&b|c  is not  a&(b|c)

```

B.3 File introduction directives

A file (or sequence) introduction directive appears at the beginning of the file. There are two different directives, one is `DECK` for normal files, the other is `KEEP` for include files (sequences). The first argument is the name of the file. The file name may not be larger than 32 characters and is converted to lower case in the general case. The optionnal following arguments may be of 2 type (and may be mixed, separated by ',')

conditional

A conditionnal is introduced by `IF=` followed by a conditionnal expression described in Section B.2 [Conditional expressions], page 51. The file is preprocessed if the conditionnal expression is true.

language specification

A language specification is introduced by a `T=`. The most common languages are ‘`mtn`’ for the mortran, ‘`ftn`’ for fortran not preprocessed, ‘`f77`’ for preprocessed fortran, ‘`c`’ for the c language and ‘`txt`’ for text files. In general the language of the file determines the name of files the preprocessed file is extracted to, the comment style and the command for inclusions.

It is a common practice to have wrong language type in `KEEP` as the language may be determined from the `DECK` that include them with `cmz`, or from their file name with `make`. This is not recommended and considered a bad practice.

Such a directive will always appear in `cmz`, as it is built-in. It is recommended to have one when using `make` too, even though it is not required in most cases. Indeed `make` uses the file name directly and finds the language and file type by looking at the file extension. `make` should then pass the language type with a `--lang lang` command line switch when calling the `cmz` directives preprocessor. With `make`, the convention is to have ‘`cm`’ added before the normal file suffix and after the ‘`.`’. The table table 3.2 shows the matching between suffixes, file type and file language.

For example, a file beginning with

```
+Deck, subroutine_foo, If=monitor&-simple, T=f77.
```

is a main preprocessed fortran file that will only be generated if ‘`monitor`’ is selected and ‘`simple`’ is not selected. The file to be preprocessed by `make` should have the ‘`.cmF`’ suffix, and be called ‘`subroutine_foo.cmF`’.

A file beginning with

```
+KEEP,inc_common,If=monitor|interface,T=mtn
```

is an mortran include file that should be processed only if ‘`monitor`’ or ‘`interface`’ is selected. The file to be preprocessed by `make` should have the ‘`cmmti`’ suffix and be called ‘`inc_common.cmmti`’. The resulting file when `make` is used will be called ‘`inc_common.mti`’.

B.4 Conditional directives

Conditional directives may be used to conditionnaly skip blocks of code. There are 4 conditional directives: `if`, `elseif`, `else` and `endif`. `+if` begins a conditional directives sequence, with argument a conditional expression. If the expression is true the block of code following the `+if` is output in the resulting file, up to another conditional directive, if it is false the code block is skipped. If the expression is false and the following conditional directive is `+elseif`, the same procedure is followed with the argument of `+elseif` which is also a conditionnal expression. More than one `+elseif` may follow a `+if`. If a `+if` or `+elseif` expression is true the following code block is output and all the following `+elseif` code blocks are skipped. If all the `+if` and `+elseif` expressions are false and the following conditionnal directive is `+else` then the block following the `+else` is output. If a previous expression was true the code block following the `+else` is skipped. The last code block is closed by `+endif`.

Conditionnal directives may be nested, a `+if` begins a deeper conditionnal sequences directives that is ended by the corresponding `+endif`.

The simplest example is:

```

    some code;
+IF,monitor
    code output only if monitor is true;
+ENDIF

```

If 'monitor' is selected, the +if block is output, it leads to

```

    some code;
    code output only if monitor is true;

```

If 'monitor' isn't selected the +if block is skipped, it leads to

```

    some code;

```

An example with +else may be:

```

+IF,double
    call dmymsub(eta);
+ELSE
    call smymsub(eta);
+ENDIF

```

If 'double' is selected the code output is call dmymsub(eta);, if 'double' isn't selected the code output is call smymsub(eta);.

Here is a self explanatory example of use of +elseif:

```

+IF,monitor
    code used if monitor is selected;
+ELSEIF,kalman
    code used if kalman is selected and monitor is not;
+ELSE
    code used if kalman and monitor are not selected;
+ENDIF

```

And last an example of nested conditional directives:

```

+IF,monitor
    code used if monitor is selected;
+_IF,kalman. deep if
    code used if monitor and kalman are selected;
+_ELSE. deep else
    code used if monitor is selected and kalman is not;
+_ENDIF. end the deep conditionnals sequence
+ELSE
    code used if monitor is not selected;
+_IF,kalman
    code used if monitor is not selected but kalman is;
+_ELSE
    code used if monitor and kalman are not selected;
+_ENDIF
    other code used if monitor is not selected;
+ENDIF

```

B.5 File inclusion directive

The file (sequence) inclusion directive is `seq`. The argument of `seq` is an include files ‘,’ separated list. The include files are `Keep` in `cmz`. The following optional arguments may be mixed:

conditional

A conditionnal is introduced by `IF=` followed by a conditionnal expression described in Section B.2 [Conditional expressions], page 51. The directive is ignored if the conditionnal expression is false.

`T=noinclude`

When this argument is present the text of the sequence will always be included in the file where the `+seq` appears.

When there is no `T=noinclude` argument, the `+seq` directive may be replaced with an inclusion command suitable for the language of the file being processed, if such command has been specified.

For example if we have the following sequence

```
+KEEP,inc,lang=C
typedef struct incstr {char* msg};
```

And the following code in the file being processed:

```
+DECK,mainf,lang=C
+SEQ,inc
int main (int argc, char* argv) { exit(0); }
```

the processing of ‘`mainf`’ should lead to the file ‘`mainf.c`’, containing an include command for ‘`inc`’:

```
#include "inc.h"
int main (int argc, char* argv) { exit(0); }
```

In case the `+seq` has the `T=noinclude`:

```
+DECK,mainf,lang=C
+SEQ,inc,T=noinclude
int main (int argc, char* argv) { exit(0); }
```

The processing of ‘`mainf`’ should lead to the file ‘`mainf.c`’ containing the text of ‘`inc`’:

```
typedef struct incstr {char* msg};
int main (int argc, char* argv) { exit(0); }
```

B.6 The ‘self’ directive

The `self` directive is an obsolete directive that may be used for conditionnal skipping of code. For a better approach see Section B.4 [Conditional directives], page 52. The optional argument of `+SELF` is `If=` followed by a conditionnal expression. If the conditionnal expression is true the code following the directive is output, if it is false the code is skipped up to any directive (including another `+SELF`) except `+seq`.

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