AMICI

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1 AMICI 0.1 General Documentation

1.1 Introduction

AMICI is a MATLAB interface for the `SUNDIALS` solvers CVODES (for ordinary differential equations) and IDAS (for algebraic differential equations). AMICI allows the user to specify differential equation models in terms of symbolic variables in MATLAB and automatically compiles such models as .mex simulation files. In contrast to the SUNDIALSTB interface, all necessary functions are transformed into native C code, which allows for a significantly faster numerical integration. Beyond forward integration, the compiled simulation file also allows for first and second order forward sensitivity analysis, steady state sensitivity analysis and adjoint sensitivity analysis for likelihood based output functions.

The interface was designed to provide routines for efficient gradient computation in parameter estimation of biochemical reaction models but is also applicable to a wider range of differential equation constrained optimization problems.

1.2 Availability

The sources for AMICI are accessible as

- Source `tarball`
- Source `zipball`
- GIT repository on `github`

Once you've obtained your copy check out the Installation

1.2.1 Obtaining AMICI via the GIT versioning system

In order to always stay up-to-date with the latest AMICI versions, simply pull it from our GIT repository and recompile it when a new release is available. For more information about GIT checkout their `website`

The GIT repository can currently be found at `https://github.com/FFroehlich/AMICI` and a direct clone is possible via

```
git clone https://github.com/FFroehlich/AMICI.git AMICI
```

1.2.2 License Conditions

This software is available under the `BSD license`

1.3 Installation

If AMICI was downloaded as a zip, it needs to be unpacked in a convenient directory. If AMICI was obtained via cloning of the git repository, no further unpacking is necessary.

To use AMICI, start MATLAB and add the AMICI direcory to the MATLAB path. To add all toolbox directories to the MATLAB path, execute the matlab script

```
installToolbox.m
```

To store the installation for further MATLAB session, the path can be saved via

```
savepath
```

For the compilation of .mex files, MATLAB needs to be configured with a working C compiler. The C compiler needs to be installed and configured via:

```
mex -setup c
```

For a list of supported compilers we refer to the mathworks documentation: mathworks.de

The tools SUNDIALS and SuiteSparse shipped with AMICI do **not** require further installation.

AMICI uses the following packages from SUNDIALS:

CVODES: the sensitivity-enabled ODE solver in SUNDIALS. Radu Serban and Alan C. Hindmarsh. *ASME 2005 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.* American Society of Mechanical Engineers, 2005. PDF

IDAS

AMICI uses the following packages from SuiteSparse:

Algorithm 907: KLU, A Direct Sparse Solver for Circuit Simulation Problems. Timothy A. Davis, Ekanathan Palamadai Natarajan, *ACM Transactions on Mathematical Software*, Vol 37, Issue 6, 2010, pp 36:1 - 36:17. PDF

Algorithm 837: AMD, an approximate minimum degree ordering algorithm, Patrick R. Amestoy, Timothy A. Davis, Iain S. Duff, *ACM Transactions on Mathematical Software*, Vol 30, Issue 3, 2004, pp 381 - 388. PDF

Algorithm 836: COLAMD, a column approximate minimum degree ordering algorithm, Timothy A. Davis, John R. Gilbert, Stefan I. Larimore, Esmond G. Ng *ACM Transactions on Mathematical Software*, Vol 30, Issue 3, 2004, pp 377 - 380. PDF

2 Model Definition & Simulation

In the following we will give a detailed overview how to specify models in AMIWRAP and how to call the generated simulation files.

2.1 Model Definition

This guide will guide the user on how to specify models in MATLAB. For example implementations see the examples in the example directory.

2.1.1 Header

The model definition needs to be defined as a function which returns a struct with all symbolic definitions and options.

```
function [model] = example_model_syms()
```

2.1.2 Options

Set the options by specifying the respective field of the modelstruct

```
model.(fieldname) = (value)
```

The options specify default options for simulation, parametrisation and compilation. All of these options are optional.

field	description	default
.atol	absolute integration tolerance	1e-8
.rtol	relative integration tolerance	1e-8
.maxsteps	maximal number integration steps	1e-8
.param	parametrisation 'log'/'log10'/'lin'	'lin'
.debug	flag to compile with debug symbols	false
.forward	flag to activate forward sensitivities	true
.adjoint	flag to activate adjoint sensitivities	true

When set to true, the fields 'noforward' and 'noadjoint' will speed up the time required to compile the model but also disable the respective sensitivity computation.

2.1.3 States

Create the respective symbolic variables. The name of the symbolic variable can be chosen arbitrarily.

```
syms state1 state2 state3
```

Create the state vector containing all states:

```
x = [ state1 state2 state3 ];
```

2.1.4 Parameters

Create the respective symbolic variables. The name of the symbolic variable can be chosen arbitrarily. Sensitivities **will be derived** for all paramaters.

```
syms param1 param2 param3 param4 param5 param6
```

Create the parameters vector

```
p = [ param1 param2 param3 param4 param5 param6 ];
```

2.1.5 Constants

Create the respective symbolic variables. The name of the symbolic variable can be chosen arbitrarily. Sensitivities with respect to constants **will not be derived**.

```
syms const1 const2
```

Create the parameters vector

```
k = [ const1 const2 ];
```

2.1.6 Differential Equation

For time-dependent differential equations you can specify a symbolic variable for time. This **needs** to be denoted by t.

```
syms t
```

Specify the right hand side of the differential equation f or xdot

```
xdot(1) = [ const1 - param1*state1 ];
xdot(2) = [ +param2*x(1) + dirac(t-param3) - const2*x(2) ];
xdot(3) = [ param4*x(2) ];
```

or

```
f(1) = [ const1 - param1*state1 ];
f(2) = [ +param2*x(1) + dirac(t-param3) - const2*x(2) ];
f(3) = [ 2*x(2) ];
```

The specification of f or xdot may depend on States, Parameters and Constants.

For DAEs also specify the mass matrix.

```
M = [1, 0, 0;...
0, 1, 0;...
0, 0, 0];
```

The specification of M may depend on parameters and constants.

For ODEs the integrator will solve the equation $\dot{x} = f$ and for DAEs the equations $M \cdot \dot{x} = f$. AMICI will decide whether to use CVODES (for ODEs) or IDAS (for DAEs) based on whether the mass matrix is defined or not.

In the definition of the differential equation you can use certain symbolic functions. For a full list of available functions see symbolic_functions.c.

Dirac functions can be used to cause a jump in the respective states at the specified time-point. This is typically used to model injections, or other external stimuli. Spline functions can be used to model time/state dependent response with unkown time/state dependence.

2.1.7 Initial Conditions

Specify the initial conditions. These may depend on Parameters on Constants and must have the same size as x.

```
x0 = [ param4, 0, 0 ];
```

2.1.8 Observables

Specify the observables. These may depend on Parameters and Constants.

```
y(1) = state1 + state2;
y(2) = state3 - state2;
```

In the definition of the observable you can use certain symbolic functions. For a full list of available functions see symbolic_functions.c. Dirac functions in observables will have no effect.

2.1.9 Events

Specifying events is optional. Events are specified in terms of a root function. Events are defined to happen at the roots of the root function.

```
root(1) = state1 - state2;
```

Events may depend on States, Parameters and Constants but **not** on Observables

2.1.10 Standard Deviation

Specifying of standard deviations is optional. It only has an effect when computing adjoint sensitivities. It allows the user to specify standard deviations of experimental data for Observables and Events.

Standard deviaton for observable data is denoted by sigma_y

```
sigma_y(1) = param5;
```

Standard deviaton for event data is denoted by sigma_y

```
sigma_t(1) = param6;
```

Both sigma_y and sigma_t can either be a scalar or of the same dimension as the Observables / Events function. They can depend on time and Parameters but must not depend on the States or Observables. The values provided in sigma_y and sigma_t will only be used if the value in Sigma_Y or Sigma_T in the user-provided data struct is NaN. See Model Simulation for details.

2.1.11 Attach to Model Struct

Eventually all symbolic expressions need to be attached to the model struct.

```
model.sym.x = x;
model.sym.k = k;
model.sym.root = root;
model.sym.xdot = xdot;
% or
model.sym.f = f;
model.sym.M = M; %only for DAEs
model.sym.p = p;
model.sym.x0 = x0;
model.sym.y = y;
model.sym.sigma_y = sigma_y;
model.sym.sigma_t = sigma_t;
```

2.2 Model Compilation

The model can then be compiled by calling amiwrap:

```
amiwrap(modelname,'example_model_syms',dir,o2flag)
```

Here modelname should be a string defining the modelname, dir should be a string containing the path to the directory in which simulation files should be placed and o2flag is a flag indicating whether second order sensitivities should also be compiled. The user should make sure that the previously defined function 'example_model_syms' is in the user path. Alternatively, the user can also call the function 'example_model_syms'

```
[model] = example_model_syms()
```

and subsequently provide the generated struct to amiwrap(), instead of providing the symbolic function:

```
amiwrap(modelname,model,dir,o2flag)
```

In a similar fashion, the user could also generate multiple model and pass them directly to amiwrap() without generating respective model definition scripts.

See also

amiwrap()

2.3 Model Simulation

After the call to amiwrap() two files will be placed in the specified directory. One is a am_*modelname*.mex and the other is simulate_*modelname*.m. The mex file should never be called directly. Instead the MATLAB script, which acts as a wrapper around the .mex simulation file should be used.

The simulate_*modelname*.m itself carries extensive documentation on how to call the function, what it returns and what additional options can be specified. In the following we will give a short overview of possible function calls.

2.3.1 Integration

Define a time vector:

```
t = linspace(0,10,100)
```

Generate a parameter vector:

```
theta = ones(6,1);
```

Generate a constants vector:

```
kappa = ones(2,1);
```

Integrate:

```
sol = simulate_modelname(t,theta,kappa,[],options)
```

The integration status will be indicated by the sol.status flag. Negative values indicated failed integration. The states will then be available as sol.x. The observables will then be available as sol.y. The events will then be available as sol.root. If no event occured there will be an event at the end of the considered interval with the final value of the root function stored in sol.rval.

Alternatively the integration call also be called via

```
[status,t,x,y] = simulate_modelname(t,theta,kappa,[],options)
```

The integration status will be indicated by the status flag. Negative values indicated failed integration. The states will then be available as x. The observables will then be available as y. No event output will be given.

2.3.2 Forward Sensitivities

Define a time vector:

```
t = linspace(0,10,100)
```

Generate a parameter vector:

```
theta = ones(6,1);
```

Generate a constants vector:

```
kappa = ones(2,1);
```

Set the sensitivity computation to forward sensitivities and Integrate:

```
options.sensi = 1;
options.forward = true;
sol = simulate_modelname(t,theta,kappa,[],options)
```

The integration status will be indicated by the sol.status flag. Negative values indicated failed integration. The states will then be available as sol.x, with the derivative with respect to the parameters in sol.sx. The observables will then be available as sol.y, with the derivative with respect to the parameters in sol.sy. The events will then be available as sol.root, with the derivative with respect to the parameters in sol.sroot. If no event occured there will be an event at the end of the considered interval with the final value of the root function stored in sol.rootval, with the derivative with respect to the parameters in sol.srootval

Alternatively the integration call also be called via

```
[status,t,x,y,sx,sy] = simulate_modelname(t,theta,kappa,[],options)
```

The integration status will be indicated by the status flag. Negative values indicated failed integration. The states will then be available as x, with derivative with respect to the parameters in sx. The observables will then be available as y, with derivative with respect to the parameters in sy. No event output will be given.

2.3.3 Adjoint Sensitivities

Define a time vector:

```
t = linspace(0,10,100)
```

Generate a parameter vector:

```
theta = ones(6,1);
```

Set the sensitivity computation to adjoint sensitivities:

```
options.sensi = 1;
options.adjoint = true;
```

Define Experimental Data:

```
D.Y = [NaN(1,2)],ones(length(t)-1,2)];
D.Sigma_Y = [0.1*ones(length(t)-1,2),NaN(1,2)];
D.T = ones(1,1);
D.Sigma_T = NaN;
```

The NaN values in Sigma_Y and Sigma_T will be replaced by the specification in Standard Deviation. Data points with NaN value will be completely ignored.

Generate a constants vector:

```
kappa = ones(2,1);
```

Integrate:

```
sol = simulate_modelname(t,theta,kappa,D,options)
```

The integration status will be indicated by the sol.status flag. Negative values indicated failed integration. The log-likelihood will then be available as sol.llh and the derivative with respect to the parameters in sol.sllh. Notice that for adjoint sensitivities no state, observable and event sensitivities will be available. Yet this approach can be expected to be significantly faster for systems with a large number of parameters.

2.3.4 Steady State Sensitivities

This will compute state sensitivities according to the formula $s_k^x = -\left(\frac{\partial f}{\partial x}\right)^{-1} \frac{\partial f}{\partial \theta_k}$

In the current implementation this formulation does not allow for conservation laws as this would result in a singular Jacobian.

Define a final timepoint t:

```
t = 100
```

Generate a parameter vector:

```
theta = ones(6,1);
```

Generate a constants vector:

```
kappa = ones(2,1);
```

Set the sensitivity computation to steady state sensitivities:

```
options.sensi = 1;
options.ss = 1;
```

Integrate:

```
sol = simulate_modelname(t,theta,kappa,D,options)
```

The states will then be available as sol.x, with the derivative with respect to the parameters in sol.sx. The observables will then be available as sol.y, with the derivative with respect to the parameters in sol.sy. Notice that for steady state sensitivities no event sensitivities will be available. For the accuracy of the computed derivatives it is essential that the system is sufficiently close to a steady state. This can be checked by examining the right hand side of the system at the final time-point via sol.xdot.

3 Code Organization

In the following we will briefly outline what happens when a model is compiled. For a more detailed description we refer the reader to the documentation of the individual functions.

After specifying a model (see Model Definition) the user will typically compile the model by invoking amiwrap(). amiwrap() first instantiates an object of the class amimodel. The properties of this object are initialised based on the user-defined model. If the o2flag is active, all subsequent computations will also be carried out on the augmented system, which also includes the equations for forward sensitivities. This allows the computation of second order sensitivities in a forward-forward approach. A forward-adjoint approach will be implemented in the future.

The sym and fun fields of this object will then be populated by amimodel::parseModel(). The amimodel::sym field contains all necessary symbolic expression while the amimodel::fun field will contain flags for all functions whether the C code for a certain function needs to be regenerated or not. The set of functions to be considered will depend on the user specification of the model fields amimodel::adjoint and amimodel::forward (see Options) as well as the employed solver (CVODES or IDAS, see Differential Equation). For all considered functions amimodel::parseModel() will check their dependencies via amimodel::checkDeps(). These dependencies are a subset of the user-specified fields of amimodel::sym (see Attach to Model Struct). amimodel::parseModel() compares the hashes of all dependencies against the amimodel::HTable of possible previous compilations and will only compute necessary symbolic expressions if changes in these fields occured. If changes in the dependencies occured, also the respective subfield in amimodel::fun be set to 1, indicating the necessity of regeneration of respective C code.

For all functions for which amimodel::fun is set to 1, amimodel::generateC() will generate C files. These files together with their respective header files will be placed in $AMICIDIR/models/*modelname*. amimodel::generateC() will also generate wrapfunctions.h and wrapfunctions.c. These files define and declare model unspecific wrapper functions around model specific functions. This construction allows us to use to build multiple different models against the same simulation routines by linking different realisations of these wrapper functions.

All the generated C functions are subsequently compiled by amimodel::compileC(). For all functions individual object files are created to reduce the computation cost of code optimization. Moreover necessary code from sundials and SuiteSparse is compiled as object files and placed in /models/*mexext*, where mexext stands for the string returned by matlab to the command mexext. The mex simulation file is compiled from amiwrap.c, linked against all object necessary of sundials, SuiteSparse and model specific functions. Depending on the required solver, the compilation will either include cvodewrap.h or idawrap.h. These files implement solver specific realisations of the AMI... functions used in amiwrap.c and amici.c. This allows the use of the same simulation routines for both CVODES and IDAS.

4 Class Index

4.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

5 Class Documentation

5.1 amimodel Class Reference

amimodel is the object in which all model definitions are stored

Public Member Functions

- amimodel (::string symfun,::string modelname)

  constructor of the amimodel class. this function initializes the model object based on the provided symfun and modelname
- mlhsInnerSubst< matlabtypesubstitute > parseModel ()

  parseModel parses the this and computes all necessary symbolic expressions.
- mlhsInnerSubst< matlabtypesubstitute > generateC ()

  generateC generates the c files which will be used in the compilation.
- mlhsInnerSubst< matlabtypesubstitute > compileC ()

  compileC compiles the mex simulation file
- mlhsInnerSubst< matlabtypesubstitute > writeCcode_sensi (::symbolic svar,::fileid fid)

  writeCcode_sensi is a wrapper for writeCcode which loops over parameters and reduces overhead by check nonzero values
- mlhsInnerSubst< matlabtypesubstitute > writeCcode (::string funstr,::fileid fid, matlabtypesubstitute ip, matlabtypesubstitute jp)

  writeCcode is a wrapper for this.gccode which initialises data and reduces overhead by check nonzero values
- mlhsInnerSubst< matlabtypesubstitute > gccode (::symbolic csym,::string funstr,::string cvar,::fileid fid)

  gccode transforms symbolic expressions into c code and writes the respective expression into a specified file
- mlhsInnerSubst< matlabtypesubstitute > generateM (::amimodel amimodelo2)

  generateM generates the matlab wrapper for the compiled C files.
- mlhsInnerSubst< matlabtypesubstitute > getFun (::struct HTable,::string funstr)

  getFun generates symbolic expressions for the requested function.
- mlhsInnerSubst< matlabtypesubstitute > getFunDeps (::string funstr)

  getDeps returns the dependencies for the requested function/expression.
- mlhsInnerSubst< matlabtypesubstitute > getFunArgs (::string funstr)

  getfunargs returns a string which contains all input arguments for the function fun.
- mlhsInnerSubst< matlabtypesubstitute > getFunCVar (::string funstr)

  getDeps returns the c variable for the requested function.
- mlhsInnerSubst< matlabtypesubstitute > getFunSVar (::string funstr)

  getDeps returns the symbolic variable for the requested function.
- mlhsSubst< mlhsInnerSubst< matlabtypesubstitute >,mlhsInnerSubst< matlabtypesubstitute > > checkDeps (::struct HTable,::cell deps)

  checkDeps checks the dependencies of functions and populates sym fields if necessary

- mlhsSubst< mlhsInnerSubst< matlabtypesubstitute >,mlhsInnerSubst< matlabtypesubstitute > > loadOld-Hashes ()

    loadOldHashes loads information from a previous compilation of the model.
- mlhsInnerSubst< matlabtypesubstitute > augmento2 ()

    augmento2 augments the system equation to also include equations for sensitivity equation. This will enable us to compute second order sensitivities in a forward-adjoint or forward-forward apporach later on.

Public Attributes

- ::struct sym

    symbolic definition struct
- ::struct fun

    struct which stores information for which functions c code needs to be generated
- ::struct strsym

    short names for symbolic variables
- ::string modelname

    name of the model
- ::struct HTable

    struct that contains hash values for the symbolic model definitions
- ::double atol = 1e-8

    default absolute tolerance
- ::double rtol = 1e-8

    default relative tolerance
- ::int maxsteps = 1e4

    default maximal number of integration steps
- ::bool debug = false

    flag indicating whether debugging symbols should be compiled
- ::bool adjoint = true

    flag indicating whether adjoint sensitivities should be enabled
- ::bool forward = true

    flag indicating whether forward sensitivities should be enabled
- ::double t0 = 0

    default initial time
- ::string wtype

    type of wrapper (cvodes/idas)
- ::int nx

    number of states
- ::int nxtrue = 0

    number of original states for second order sensitivities
- ::int ny

    number of observables
- ::int nytrue = 0

    number of original observables for second order sensitivities
- ::int nr

    number of events
- ::int ndisc

    number of discontinuities
- ::int np

    number of parameters
- ::int nk

    number of constants

- ::*int id

  flag for DAEs
- ::int ubw

  upper Jacobian bandwidth
- ::int lbw

  lower Jacobian bandwidth
- ::int nnz

  number of nonzero entries in Jacobian
- ::*int sparseidx

  dataindexes of sparse Jacobian
- ::*int rowvals

  rowindexes of sparse Jacobian
- ::*int colptrs

  columnindexes of sparse Jacobian
- ::*int sparseidxB

  dataindexes of sparse Jacobian
- ::*int rowvalsB

  rowindexes of sparse Jacobian
- ::*int colptrsB

  columnindexes of sparse Jacobian
- ::*cell funs

  cell array of functions to be compiled
- ::string coptim = "-O3"

  optimisation flag for compilation
- ::string param = "lin"

  default parametrisation

5.1.1 Detailed Description

Definition at line 17 of file amimodel.m.

5.1.2 Constructor & Destructor Documentation

5.1.2.1 amimodel (::string *symfun*, ::string *modelname*)

Parameters

symfun	this is the string to the function which generates the modelstruct. You can also directly pass the struct here
modelname	name of the model

Definition at line 279 of file amimodel.m.

5.1.3 Member Function Documentation

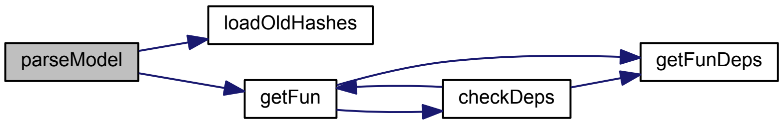
5.1.3.1 mlhsInnerSubst<::amimodel > parseModel ( )

Return values

this	updated model definition object

Definition at line 18 of file parseModel.m.

Here is the call graph for this function:



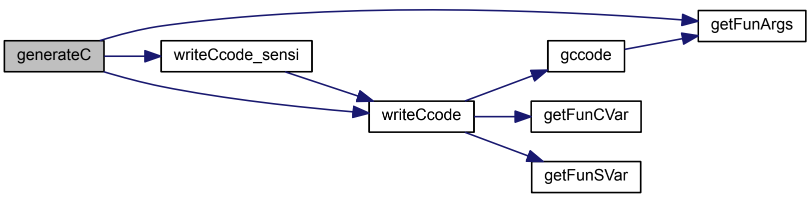
5.1.3.2 mlhsInnerSubst<::amimodel > generateC ( )

Return values

this	model definition object

Definition at line 18 of file generateC.m.

Here is the call graph for this function:



5.1.3.3 mlhsInnerSubst<::amimodel > compileC ( )

Return values

this	model definition object

Definition at line 18 of file compileC.m.

5.1.3.4 mlhsInnerSubst<::amimodel > writeCcode_sensi (::symbolic *svar*, ::fileid *fid*)

Parameters

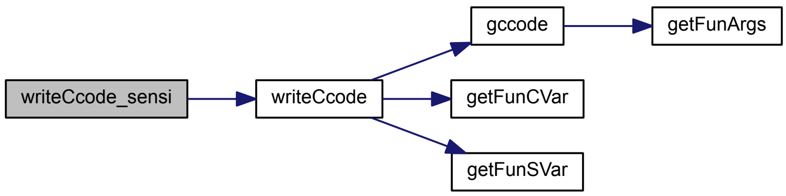
svar	symbolic variable which is later on passed to ggode
fid	file id in which the final expression is written

Return values

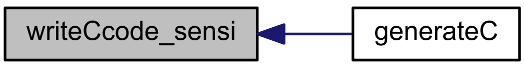
this	model definition object

Definition at line 18 of file writeCcode_sensi.m.

Here is the call graph for this function:



Here is the caller graph for this function:



5.1.3.5 mlhsInnerSubst<::amimodel > writeCcode (::string *funstr,* ::fileid *fid,* matlabtypesubstitute *ip,* matlabtypesubstitute *jp*)

Parameters

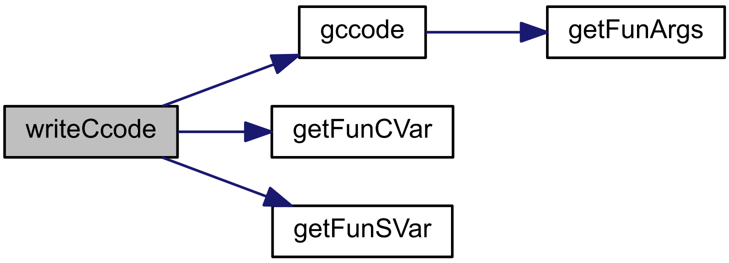
funstr	function for which C code is to be generated
fid	file id in which the final expression is written
ip	index for symbolic variable, if applicable svar(:,ip) will be passed to ggcode
jp	index for symbolic variable, if applicable svar(:,ip,jp) will be passed to ggcode

Return values

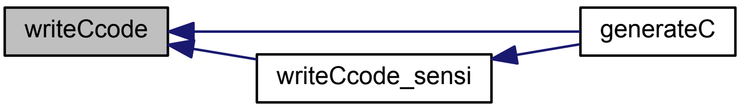
this	model definition object

Definition at line 18 of file writeCcode.m.

Here is the call graph for this function:



Here is the caller graph for this function:



5.1.3.6 mlhsInnerSubst $<$ ::**amimodel** $>$ gccode (::symbolic *csym*, ::string *funstr*, ::string *cvar*, ::fileid *fid*)

Parameters

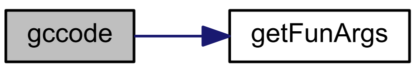
csym	symbolic expression to be transform
funstr	function for which C code is to be generated
cvar	name of the assigned variable in C
fid	file id in which the expression should be written

Return values

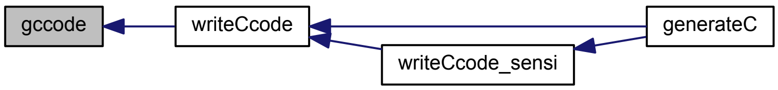
this	model definition object

Definition at line 18 of file gccode.m.

Here is the call graph for this function:



Here is the caller graph for this function:



5.1.3.7 mlhsInnerSubst<::amimodel > generateM (::amimodel *amimodelo2*)

Parameters

amimodelo2	this struct must contain all necessary symbolic definitions for second order sensivities

Return values

this	model definition object

Definition at line 18 of file generateM.m.

5.1.3.8 mlhsInnerSubst<::amimodel > getFun (::struct *HTable,* ::string *funstr*)

Parameters

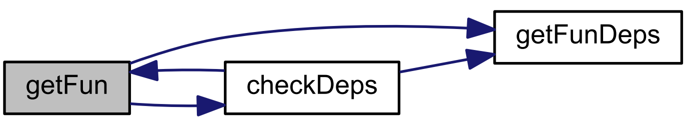
HTable	struct with hashes of symbolic definition from the previous compilation
funstr	function for which symbolic expressions should be computed

Return values

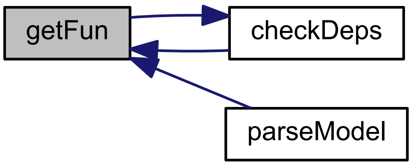
this	updated model definition object

Definition at line 18 of file getFun.m.

Here is the call graph for this function:



Here is the caller graph for this function:



5.1.3.9 mlhsInnerSubst< ::cell > getFunDeps (::string *funstr*)

Parameters

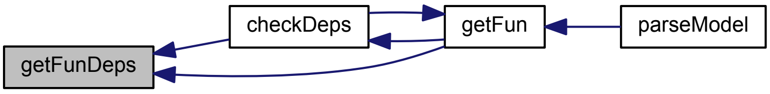
funstr	function or expression for which the dependencies should be returned

Return values

deps	cell array of dependencies

Definition at line 18 of file getFunDeps.m.

Here is the caller graph for this function:



5.1.3.10 mlhsInnerSubst< matlabtypesubstitute > getFunArgs (::string *funstr*)

Parameters

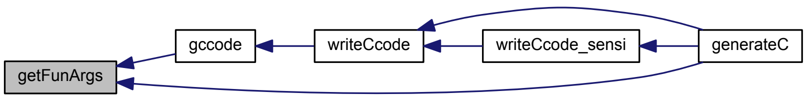
funstr	function name

Return values

str	string containing function arguments

Definition at line 18 of file getFunArgs.m.

Here is the caller graph for this function:



5.1.3.11 mlhsInnerSubst<::string > getFunCVar (::string *funstr*)

Parameters

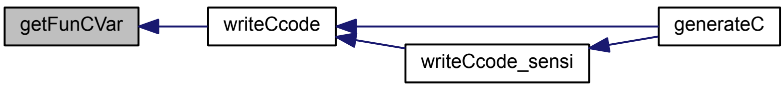
funstr	function or expression for which the dependencies should be returned

Return values

cvar	cell array of dependencies

Definition at line 18 of file getFunCVar.m.

Here is the caller graph for this function:



5.1.3.12 mlhsInnerSubst< matlabtypesubstitute > getFunSVar (::string *funstr*)

Parameters

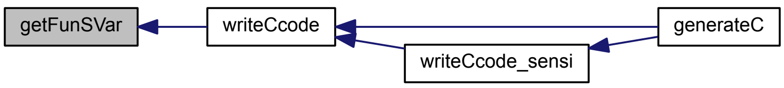
funstr	function or expression for which the dependencies should be returned

Return values

cvar	cell array of dependencies

Definition at line 18 of file getFunSVar.m.

Here is the caller graph for this function:



5.1.3.13 mlhsSubst< mlhsInnerSubst< matlabtypesubstitute >,mlhsInnerSubst<::HTable > > checkDeps (::struct *HTable,* ::cell *deps*)

Parameters

HTable	struct with reference hashes of functions in its fields
deps	cell array with containing a list of dependencies

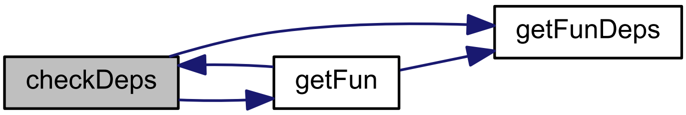
Return values

cflag	boolean indicating whether any of the dependencies have

changed with respect to the hashes stored in HTable

Definition at line 18 of file checkDeps.m.

Here is the call graph for this function:



Here is the caller graph for this function:

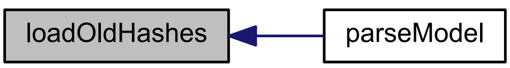
5.1.3.14 mlhsSubst< mlhsInnerSubst<::**amimodel** >,mlhsInnerSubst<::struct > > loadOldHashes ( )

Return values

this	updated model definition object
HTable	struct with hashes of symbolic definition from the previous compilation

Definition at line 18 of file loadOldHashes.m.

Here is the caller graph for this function:



5.1.3.15 mlhsInnerSubst<::amimodel > augmento2 ( )

Return values

this	augmented system which contains symbolic definition of the original system and its sensitivities

Definition at line 18 of file augmento2.m.

5.1.4 Member Data Documentation

5.1.4.1 atol = 1e-8

Default: 1e-8

Definition at line 61 of file amimodel.m.

5.1.4.2 rtol = 1e-8

Default: 1e-8

Definition at line 69 of file amimodel.m.

5.1.4.3 maxsteps = 1e4

Default: 1e4

Definition at line 77 of file amimodel.m.

5.1.4.4 debug = false

Default: false

Definition at line 85 of file amimodel.m.

5.1.4.5 adjoint = true

Default: true

Definition at line 93 of file amimodel.m.

5.1.4.6 forward = true

Default: true

Definition at line 101 of file amimodel.m.

5.1.4.7 t0 = 0

Default: 0

Definition at line 109 of file amimodel.m.

5.1.4.8 nxtrue = 0

Default: 0

Definition at line 131 of file amimodel.m.

5.1.4.9 nytrue = 0

Default: 0

Definition at line 146 of file amimodel.m.

5.1.4.10 coptim = "-O3"

Default: "-O3"

Definition at line 259 of file amimodel.m.

5.1.4.11 param = "lin"

Default: "lin"

Definition at line 267 of file amimodel.m.

5.2 ExpData Struct Reference

struct that carries all information about experimental data

```
#include <edata.h>
```

Public Attributes

- double ∗ am_my

  observed data
- double ∗ am_ysigma

  standard deviation of observed data
- double ∗ am_mt

  observed events
- double ∗ am_tsigma

  standard deviation of observed events

5.2.1 Detailed Description

Definition at line 18 of file edata.h.

5.3 ReturnData Struct Reference

struct that stores all data which is later returned by the mex function

```
#include <rdata.h>
```

Public Attributes

- double ∗ am_tsdata

  timepoints
- double ∗ am_xdotdata

  time derivative
- double ∗ am_dxdotdpdata

  parameter derivative of time derivative

- double * am_dydxdata

  state derivative of observables
- double * am_dydpdata

  parameter derivative of observables
- double * am_Jdata

  Jacobian of differential equation right hand side.
- double * am_rootdata

  events
- double * am_rootSdata

  parameter derivative of events
- double * am_rootS2data

  second order parameter derivative of events
- double * am_rootvaldata

  value of event function
- double * am_rootvalSdata

  parameter derivative of event function
- double * am_rootvalS2data

  second order parameter derivative of event function
- double * am_xdata

  state
- double * am_xSdata

  parameter derivative of state
- double * am_ydata

  observable
- double * am_ySdata

  parameter derivative of observable
- double * am_numstepsdata

  number of integration steps forward problem
- double * am_numstepsSdata

  number of integration steps backward problem
- double * am_numrhsevalsdata

  number of right hand side evaluations forward problem
- double * am_numrhsevalsSdata

  number of right hand side evaluations backwad problem
- double * am_orderdata

  employed order forward problem
- double * am_llhdata

  likelihood value
- double * am_chi2data

  chi2 value
- double * am_llhSdata

  parameter derivative of likelihood
- double * am_llhS2data

  second order parameter derivative of likelihood

5.3.1 Detailed Description

Definition at line 42 of file rdata.h.

5.3.2 Member Data Documentation

5.3.2.1 double∗ am_xdata

returned vector

Definition at line 69 of file rdata.h.

5.4 TempData Struct Reference

struct that provides temporary storage for different variables

`#include <tdata.h>`

Public Attributes

- realtype am_t

    current time
- N_Vector am_x

    state vector
- N_Vector am_dx

    differential state vector
- N_Vector am_xdot

    time derivative state vector
- N_Vector am_xB

    adjoint state vector
- N_Vector am_dxB

    differential adjoint state vector
- N_Vector am_xQB

    quadrature state vector
- N_Vector ∗ am_sx

    sensitivity state vector array
- N_Vector ∗ am_sdx

    differential sensitivity state vector array
- N_Vector am_id

    index indicating DAE equations vector
- DlsMat am_Jtmp

    Jacobian.
- double ∗ am_llhS0

    parameter derivative of likelihood array
- double am_g

    data likelihood
- double ∗ am_dgdp

    parameter derivative of data likelihood
- double ∗ am_dgdx

    state derivative of data likelihood
- double am_r

    event likelihood
- double ∗ am_drdp

    parameter derivative of event likelihood
- double ∗ am_drdx

    state derivative of event likelihood

- double am_rval
  root function likelihood
- double ∗ am_drvaldp
  parameter derivative of root function likelihood
- double ∗ am_drvaldx
  state derivative of root function likelihood
- double ∗ am_dtdx
  state derivative of event
- double ∗ am_dtdp
  parameter derivative of event
- double ∗ am_dydp
  parameter derivative of observable
- double ∗ am_dydx
  state derivative of observable
- double ∗ am_yS0
  initial sensitivity of observable
- double ∗ am_sigma_y
  data standard deviation
- double ∗ am_dsigma_ydp
  parameter derivative of data standard deviation
- double ∗ am_sigma_t
  event standard deviation
- double ∗ am_dsigma_tdp
  parameter derivative of event standard deviation
- double ∗ am_x_tmp
  state array
- double ∗ am_sx_tmp
  sensitivity state array
- double ∗ am_dx_tmp
  differential state array
- double ∗ am_sdx_tmp
  differential sensitivity state array
- double ∗ am_xdot_tmp
  time derivative state array
- double ∗ am_xB_tmp
  differential adjoint state array
- double ∗ am_xQB_tmp
  quadrature state array
- double ∗ am_dxB_tmp
  differential adjoint state array
- double ∗ am_id_tmp
  index indicating DAE equations array
- int ∗ am_rootsfound
  array of flags indicating which root has beend found
- double ∗ am_rootvaltmp
  array of values of the root function
- int ∗ am_rootidx
  array of index which root has been found
- int am_which
  integer for indexing of backwards problems
- double ∗ am_discs
  array containing the time-points of discontinuities
- double ∗ am_irdiscs
  array containing the index of discontinuities

5.4.1 Detailed Description

Definition at line 64 of file tdata.h.

5.4.2 Member Data Documentation

5.4.2.1 int* am_rootsfound

array of length nr with the indices of the user functions gi found to have a root. For i = 0, . . . ,nr?1, rootsfound[i]?= 0 if gi has a root, and = 0 if not.

Definition at line 151 of file tdata.h.

5.5 UserData Struct Reference

struct that stores all user provided data

`#include <udata.h>`

Public Attributes

- int ∗ am_plist

  parameter reordering
- int am_np

  number of parameters
- int am_ny

  number of observables
- int am_nx

  number of states
- int am_nr

  number of roots
- int am_nt

  number of timepoints
- int am_ndisc

  number of discontinuities
- int am_nnz

  number of nonzero entries in jacobian
- int am_nmaxroot

  maximal number of roots to collect
- int am_nmaxdisc

  maximal number of discontinuities to track
- double ∗ am_p

  parameter array
- double ∗ am_k

  constants array
- double am_tstart

  starting time
- double ∗ am_ts

  timepoints
- double ∗ am_pbar

  scaling of parameters
- double ∗ am_xbar

scaling of states
- double ∗ am_idlist

  flag array for DAE equations
- int am_sensi

  flag indicating whether sensitivities are supposed to be computed
- double am_atol

  absolute tolerances for integration
- double am_rtol

  relative tolerances for integration
- int am_maxsteps

  maximum number of allowed integration steps
- int am_ism

  internal sensitivity method
- int am_sensi_meth

  method for sensitivity computation
- int am_linsol

  linear solver specification
- int am_interpType

  interpolation type
- int am_lmm

  linear multistep method
- int am_iter

  nonlinear solver
- booleantype am_stldet

  flag controlling stability limit detection
- int am_ubw

  upper bandwith of the jacobian
- int am_lbw

  lower bandwith of the jacobian
- booleantype am_bsx0

  flag for sensitivity initialisation
- double ∗ am_sx0data

  sensitivity initialisation
- int am_event_model

  error model for events
- int am_data_model

  error model for udata
- int am_ordering

  state ordering

5.5.1 Detailed Description

Definition at line 61 of file udata.h.

5.5.2 Member Data Documentation

5.5.2.1 int am_ism

a flag used to select the sensitivity solution method. Its value can be CV SIMULTANEOUS or CV STAGGERED. Only applies for Forward Sensitivities.

Definition at line 115 of file udata.h.

5.5.2.2 int am_sensi_meth

CW_FSA for forward sensitivity analysis, CW_ASA for adjoint sensitivity analysis

Definition at line 121 of file udata.h.

5.5.2.3 int am_interpType

specifies the interpolation type for the forward problem solution which is then used for the backwards problem. can be either CV_POLYNOMIAL or CV_HERMITE

Definition at line 128 of file udata.h.

5.5.2.4 int am_lmm

specifies the linear multistep method and may be one of two possible values: CV ADAMS or CV BDF.

Definition at line 134 of file udata.h.

5.5.2.5 int am_iter

specifies the type of nonlinear solver iteration and may be either CV NEWTON or CV FUNCTIONAL.

Definition at line 140 of file udata.h.

5.5.2.6 booleantype am_bsx0

flag which determines whether analytic sensitivities initialisation or provided initialisation should be used

Definition at line 154 of file udata.h.

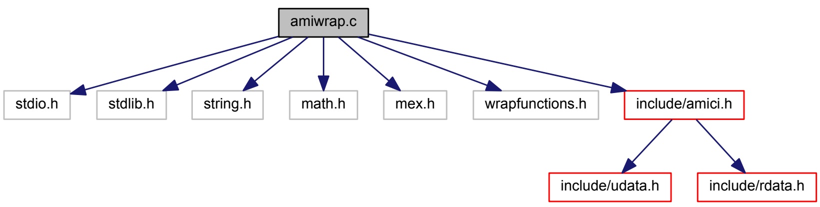
6 File Documentation

6.1 amiwrap.c File Reference

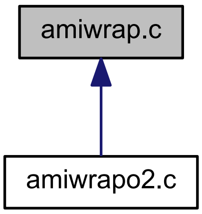
core routines for mex interface

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>
#include <mex.h>
#include "wrapfunctions.h"
#include <include/amici.h>
```

Include dependency graph for amiwrap.c:



This graph shows which files directly or indirectly include this file:



Functions

- void mexFunction (int nlhs, mxArray *plhs[ ], int nrhs, const mxArray *prhs[ ])

6.1.1 Detailed Description

This file defines the fuction mexFunction which is executed upon calling the mex file from matlab

6.1.2 Function Documentation

6.1.2.1 void mexFunction (int *nlhs*, mxArray * *plhs[ ]*, int *nrhs*, const mxArray * *prhs[ ]*)

mexFunction is the main function of the mex simulation file this function carries out all numerical integration and writes results into the sol struct.

Parameters

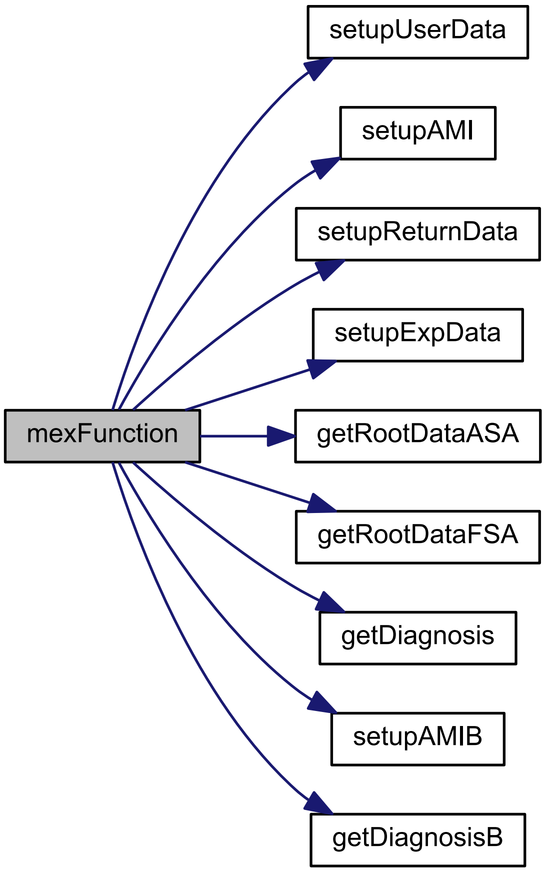
in	*nlhs*	number of output arguments of the matlab call **Type**: int
out	*plhs*	pointer to the array of output arguments **Type**: mxArray
in	*nrhs*	number of input arguments of the matlab call **Type**: int
in	*prhs*	pointer to the array of input arguments **Type**: mxArray

Returns

void

Definition at line 25 of file amiwrap.c.

Here is the call graph for this function:



6.2 amiwrap.m File Reference

AMIWRAP generates c mex files for the simulation of systems of differential equations via CVODES and IDAS.

Functions

- noret::substitute amiwrap (matlabtypesubstitute varargin)

    AMIWRAP generates c mex files for the simulation of systems of differential equations via CVODES and IDAS.

6.2.1 Function Documentation

6.2.1.1 noret::substitute amiwrap (matlabtypesubstitute *varargin*)

Parameters

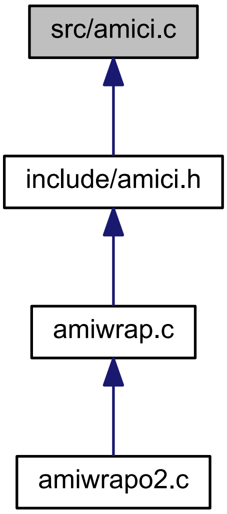
varargin	`1 amiwrap ( modelname, symfun, tdir, o2flag )` *Required Parameters for varargin:* • modelname specifies the name of the model which will be later used for the naming of the simualation file • symfun specifies a function which executes model defition see Model Definition for details • tdir target directory where the simulation file should be placed **Default:** $AMICIDIR/models/modelname • o2flag boolean whether second order sensitivities should be enabled **Default:** false

Definition at line 17 of file amiwrap.m.

6.3 src/amici.c File Reference

core routines for integration

This graph shows which files directly or indirectly include this file:



Macros

- #define amici_c

  include guard
- #define AMI_SUCCESS 0

  return value indicating successful execution

Functions

- UserData setupUserData (const mxArray *prhs[ ])
- void * setupAMI (int *status, void *user_data, void *temp_data)
- void setupAMIB (int *status, void *ami_mem, void *user_data, void *temp_data)
- ReturnData setupReturnData (const mxArray *prhs[ ], void *user_data)
- ExpData setupExpData (const mxArray *prhs[ ], void *user_data)
- void getRootDataFSA (int *status, int *nroots, void *ami_mem, void *user_data, void *return_data, void *temp_data)
- void getRootDataASA (int *status, int *nroots, int *idisc, void *ami_mem, void *user_data, void *return_data, void *exp_data, void *temp_data)
- void getDiagnosis (int *status, int it, void *ami_mem, void *user_data, void *return_data)
- void getDiagnosisB (int *status, int it, void *ami_mem, void *user_data, void *return_data, void *temp_data)

6.3.1 Function Documentation

6.3.1.1 UserData setupUserData (const mxArray * *prhs[ ]*)

setupUserData extracts information from the matlab call and returns the corresponding UserData struct

Parameters

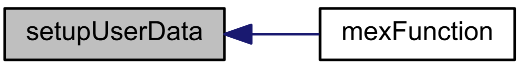
in	*prhs*	pointer to the array of input arguments **Type**: mxArray

Returns

udata: struct containing all provided user data

Definition at line 10 of file amici.c.

Here is the caller graph for this function:



6.3.1.2 void* setupAMI (int * *status,* void * *user_data,* void * *temp_data*)

setupAMIs initialises the ami memory object

Parameters

out	*status*	flag indicating success of execution **Type**: *int
in	*user_data*	pointer to the user data struct **Type**: UserData

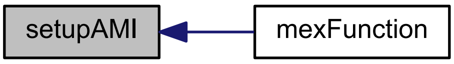
in	*temp_data*	pointer to the temporary data struct **Type**: TempData

Returns

void

Definition at line 149 of file amici.c.

Here is the caller graph for this function:



6.3.1.3 void setupAMIB (int ∗ *status*, void ∗ *ami_mem*, void ∗ *user_data*, void ∗ *temp_data*)

setupAMIB initialises the AMI memory object for the backwards problem

Parameters

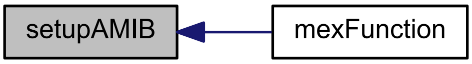
out	*status*	flag indicating success of execution **Type**: ∗int
in	*ami_mem*	pointer to the solver memory object of the forward problem
in	*user_data*	pointer to the user data struct **Type**: UserData
in	*temp_data*	pointer to the temporary data struct **Type**: TempData

Returns

void

Definition at line 434 of file amici.c.

Here is the caller graph for this function:



6.3.1.4 ReturnData setupReturnData (const mxArray ∗ *prhs[ ]*, void ∗ *user_data*)

setupReturnData initialises the return data struct

Parameters

in	*prhs*	user input **Type**: ∗mxArray
in	*user_data*	pointer to the user data struct **Type**: UserData

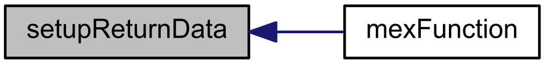
Returns

rdata: return data struct
Type: ReturnData

user udata

Definition at line 625 of file amici.c.

Here is the caller graph for this function:



6.3.1.5 ExpData setupExpData (const mxArray ∗ *prhs[ ]*, void ∗ *user_data*)

setupExpData initialises the experimental data struct

Parameters

in	*prhs*	user input **Type**: ∗mxArray
in	*user_data*	pointer to the user data struct **Type**: UserData

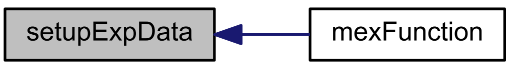
Returns

edata: experimental data struct
Type: ExpData

user udata

Definition at line 690 of file amici.c.

Here is the caller graph for this function:



6.3.1.6 void getRootDataFSA (int * *status,* int * *nroots,* void * *ami_mem,* void * *user_data,* void * *return_data,* void * *temp_data*)

getRootDataFSA extracts root information for forward sensitivity analysis

Parameters

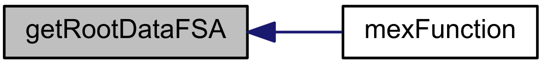
out	*status*	flag indicating success of execution **Type**: int
out	*nroots*	counter for the number of found roots **Type**: int
in	*ami_mem*	pointer to the solver memory block **Type**: void
in	*user_data*	pointer to the user data struct **Type**: UserData
out	*return_data*	pointer to the return data struct **Type**: ReturnData
out	*temp_data*	pointer to the temporary data struct **Type**: TempData

Returns

void

Definition at line 789 of file amici.c.

Here is the caller graph for this function:



6.3.1.7 void getRootDataASA (int ∗ *status*, int ∗ *nroots*, int ∗ *idisc*, void ∗ *ami_mem*, void ∗ *user_data*, void ∗ *return_data*, void ∗ *exp_data*, void ∗ *temp_data*)

getRootDataASA extracts root information for adjoint sensitivity analysis

Parameters

out	*status*	flag indicating success of execution **Type**: ∗int
out	*nroots*	counter for the number of found roots **Type**: ∗int
out	*idisc*	counter for the number of found discontinuities **Type**: ∗int
in	*ami_mem*	pointer to the solver memory block **Type**: ∗void
in	*user_data*	pointer to the user data struct **Type**: UserData
out	*return_data*	pointer to the return data struct **Type**: ReturnData
in	*exp_data*	pointer to the experimental data struct **Type**: ExpData

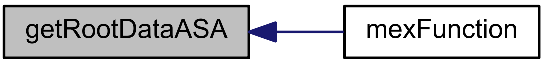
out	*temp_data*	pointer to the temporary data struct **Type**: TempData

Returns

void

Definition at line 873 of file amici.c.

Here is the caller graph for this function:



6.3.1.8 void getDiagnosis (int ∗ *status*, int *it*, void ∗ *ami_mem*, void ∗ *user_data*, void ∗ *return_data*)

getDiagnosis extracts diagnosis information from solver memory block and writes them into the return data struct

Parameters

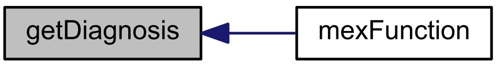
out	*status*	flag indicating success of execution **Type**: ∗int
in	*it*	time-point index **Type**: int
in	*ami_mem*	pointer to the solver memory block **Type**: ∗void
in	*user_data*	pointer to the user data struct **Type**: UserData
out	*return_data*	pointer to the return data struct **Type**: ReturnData

Returns

void

Definition at line 981 of file amici.c.

Here is the caller graph for this function:



6.3.1.9 void getDiagnosisB (int ∗ *status*, int *it*, void ∗ *ami_mem*, void ∗ *user_data*, void ∗ *return_data*, void ∗ *temp_data*)

getDiagnosis extracts diagnosis information from solver memory block and writes them into the return data struct

Parameters

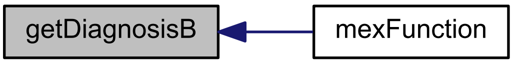
out	*status*	flag indicating success of execution **Type**: ∗int
in	*it*	time-point index **Type**: int
in	*ami_mem*	pointer to the solver memory block **Type**: ∗void
in	*user_data*	pointer to the user data struct **Type**: UserData
out	*return_data*	pointer to the return data struct **Type**: ReturnData
out	*temp_data*	pointer to the temporary data struct **Type**: TempData

Returns

void

Definition at line 1015 of file amici.c.

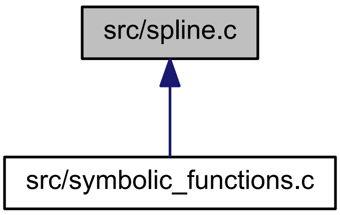
Here is the caller graph for this function:



6.4 src/spline.c File Reference

definition of spline functions

This graph shows which files directly or indirectly include this file:



Functions

- int spline (int n, int end1, int end2, double slope1, double slope2, double x[ ], double y[ ], double b[ ], double c[ ], double d[ ])

- double seval (int n, double u, double x[ ], double y[ ], double b[ ], double c[ ], double d[ ])
- double deriv (int n, double u, double x[ ], double b[ ], double c[ ], double d[ ])
- double sinteg (int n, double u, double x[ ], double y[ ], double b[ ], double c[ ], double d[ ])

6.4.1 Detailed Description

Author

Peter & Nigel, Design Software, 42 Gubberley St, Kenmore, 4069, Australia.

6.4.2 Function Documentation

6.4.2.1 int spline (int *n*, int *end1*, int *end2*, double *slope1*, double *slope2*, double *x[ ]*, double *y[ ]*, double *b[ ]*, double *c[ ]*, double *d[ ]*)

Evaluate the coefficients b[i], c[i], d[i], i = 0, 1, .. n-1 for a cubic interpolating spline

S(xx) = Y[i] + b[i] ∗ w + c[i] ∗ w∗∗2 + d[i] ∗ w∗∗3 where w = xx - x[i] and x[i] <= xx <= x[i+1]

The n supplied data points are x[i], y[i], i = 0 ... n-1.

Parameters

in	*n*	The number of data points or knots (n >= 2)
in	*end1*	0: default condition 1: specify the slopes at x[0]
in	*end2*	0: default condition 1: specify the slopes at x[n-1]
in	*slope1*	slope at x[0]
in	*slope2*	slope at x[n-1]
in	*x[ ]*	the abscissas of the knots in strictly increasing order
in	*y[ ]*	the ordinates of the knots
out	*b[ ]*	array of spline coefficients
out	*c[ ]*	array of spline coefficients
out	*d[ ]*	array of spline coefficients

Return values

0	normal return
1	less than two data points; cannot interpolate
2	x[] are not in ascending order

Notes

- The accompanying function seval() may be used to evaluate the spline while deriv will provide the first derivative.
- Using p to denote differentiation y[i] = S(X[i]) b[i] = Sp(X[i]) c[i] = Spp(X[i])/2 d[i] = Sppp(X[i])/6 (Derivative from the right)
- Since the zero elements of the arrays ARE NOW used here, all arrays to be passed from the main program should be dimensioned at least [n]. These routines will use elements [0 .. n-1].
- Adapted from the text Forsythe, G.E., Malcolm, M.A. and Moler, C.B. (1977) "Computer Methods for Mathematical Computations" Prentice Hall
- Note that although there are only n-1 polynomial segments, n elements are requird in b, c, d. The elements b[n-1], c[n-1] and d[n-1] are set to continue the last segment past x[n-1].

Definition at line 66 of file spline.c.

6.4.2.2 double seval (int *n*, double *u*, double *x[ ]*, double *y[ ]*, double *b[ ]*, double *c[ ]*, double *d[ ]*)

Evaluate the cubic spline function

S(xx) = y[i] + b[i] ∗ w + c[i] ∗ w∗∗2 + d[i] ∗ w∗∗3 where w = u - x[i] and x[i] <= u <= x[i+1] Note that Horner's rule is used. If u < x[0] then i = 0 is used. If u > x[n-1] then i = n-1 is used.

Parameters

in	*n*	The number of data points or knots (n >= 2)
in	*u*	the abscissa at which the spline is to be evaluated
in	*x[ ]*	the abscissas of the knots in strictly increasing order
in	*y[ ]*	the ordinates of the knots
in	*b*	array of spline coefficients computed by spline().
in	*c*	array of spline coefficients computed by spline().
in	*d*	array of spline coefficients computed by spline().

Returns

the value of the spline function at u

Notes

- If u is not in the same interval as the previous call then a binary search is performed to determine the proper interval.

Definition at line 208 of file spline.c.

6.4.2.3 double deriv (int *n*, double *u*, double *x[ ]*, double *b[ ]*, double *c[ ]*, double *d[ ]*)

Evaluate the derivative of the cubic spline function

S(x) = B[i] + 2.0 ∗ C[i] ∗ w + 3.0 ∗ D[i] ∗ w∗∗2 where w = u - X[i] and X[i] <= u <= X[i+1] Note that Horner's rule is used. If U < X[0] then i = 0 is used. If U > X[n-1] then i = n-1 is used.

Parameters

in	*n*	the number of data points or knots (n >= 2)
in	*u*	the abscissa at which the derivative is to be evaluated
in	*x*	the abscissas of the knots in strictly increasing order
in	*b*	array of spline coefficients computed by spline()
in	*c*	array of spline coefficients computed by spline()
in	*d*	array of spline coefficients computed by spline()

Returns

the value of the derivative of the spline function at u

Notes

- If u is not in the same interval as the previous call then a binary search is performed to determine the proper interval.

Definition at line 264 of file spline.c.

6.4.2.4 double sinteg (int *n*, double *u*, double *x[ ]*, double *y[ ]*, double *b[ ]*, double *c[ ]*, double *d[ ]*)

Integrate the cubic spline function

S(xx) = y[i] + b[i] ∗ w + c[i] ∗ w∗∗2 + d[i] ∗ w∗∗3 where w = u - x[i] and x[i] <= u <= x[i+1]

The integral is zero at u = x[0].

If u < x[0] then i = 0 segment is extrapolated. If u > x[n-1] then i = n-1 segment is extrapolated.

Parameters

in	*n*	the number of data points or knots (n >= 2)
in	*u*	the abscissa at which the spline is to be evaluated
in	*x[ ]*	the abscissas of the knots in strictly increasing order
in	*y[ ]*	the ordinates of the knots
in	*b*	array of spline coefficients computed by spline().
in	*c*	array of spline coefficients computed by spline().
in	*d*	array of spline coefficients computed by spline().

Returns

the value of the spline function at u

Notes

- If u is not in the same interval as the previous call then a binary search is performed to determine the proper interval.

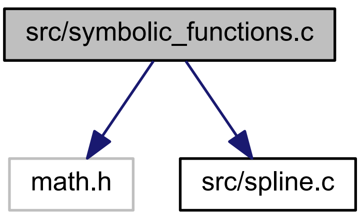
Definition at line 324 of file spline.c.

6.5 src/symbolic_functions.c File Reference

definition of symbolic functions

```
#include <math.h>
#include <src/spline.c>
```

Include dependency graph for symbolic_functions.c:



Macros

- #define amici_symbolic_functions_c

  include guard
- #define TRUE 1

  bool return value true
- #define FALSE 0

  bool return value false

Functions

- int am_ge (double a, double b)

- int Dam_ge (int id, double a, double b)
- int am_gt (double a, double b)
- int Dam_gt (int id, double a, double b)
- int am_le (double a, double b)
- int Dam_le (int id, double a, double b)
- int am_lt (double a, double b)
- int Dam_lt (int id, double a, double b)
- double am_if (int condition, double truepart, double falsepart)
- double Dam_if (int id, int condition, double truepart, double falsepart)
- int am_and (int a, int b)
- double Dam_and (int id, int a, int b)
- int am_or (int a, int b)
- double Dam_or (int id, int a, int b)
- double am_min (double a, double b)
- double Dam_min (int id, double a, double b)
- double am_max (double a, double b)
- double Dam_max (int id, double a, double b)
- double heaviside (double x)
- double dirac (double x)
- double Ddirac (int id, double x)
- double spline3 (double t, double t1, double p1, double t2, double p2, double t3, double p3, int ss, double dudt)
- double spline_pos3 (double t, double t1, double p1, double t2, double p2, double t3, double p3, int ss, double dudt)
- double spline4 (double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, int ss, double dudt)
- double spline_pos4 (double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, int ss, double dudt)
- double spline5 (double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, double t5, double p5, int ss, double dudt)
- double spline_pos5 (double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, double t5, double p5, int ss, double dudt)
- double spline10 (double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, double t5, double p5, double t6, double p6, double t7, double p7, double t8, double p8, double t9, double p9, double t10, double p10, int ss, double dudt)
- double spline_pos10 (double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, double t5, double p5, double t6, double p6, double t7, double p7, double t8, double p8, double t9, double p9, double t10, double p10, int ss, double dudt)
- double Dspline3 (int id, double t, double t1, double p1, double t2, double p2, double t3, double p3, int ss, double dudt)
- double Dspline_pos3 (int id, double t, double t1, double p1, double t2, double p2, double t3, double p3, int ss, double dudt)
- double Dspline4 (int id, double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, int ss, double dudt)
- double Dspline_pos4 (int id, double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, int ss, double dudt)
- double Dspline5 (int id, double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, double t5, double p5, int ss, double dudt)
- double Dspline_pos5 (int id, double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, double t5, double p5, int ss, double dudt)
- double Dspline10 (int id, double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, double t5, double p5, double t6, double p6, double t7, double p7, double t8, double p8, double t9, double p9, double t10, double p10, int ss, double dudt)
- double Dspline_pos10 (int id, double t, double t1, double p1, double t2, double p2, double t3, double p3, double t4, double p4, double t5, double p5, double t6, double p6, double t7, double p7, double t8, double p8, double t9, double p9, double t10, double p10, int ss, double dudt)

6.5.1 Detailed Description

This file contains definitions of various symbolic functions which

6.5.2 Function Documentation

6.5.2.1 int am_ge (double *a*, double *b*)

c implementation of matlab function ge

Parameters

a	value1 **Type**: double
b	value2 **Type**: double

Returns

if(a >= 0) then 1 else 0
Type: int

Definition at line 27 of file symbolic_functions.c.

6.5.2.2 int Dam_ge (int *id*, double *a*, double *b*)

parameter derivative of c implementation of matlab function ge

Parameters

id	argument index for differentiation
a	value1 **Type**: double
b	value2 **Type**: double

Returns

0

Definition at line 44 of file symbolic_functions.c.

6.5.2.3 int am_gt (double *a*, double *b*)

c implementation of matlab function gt

Parameters

a	value1 **Type**: double
b	value2 **Type**: double

Returns

if(a > 0) then 1 else 0
Type: int

Definition at line 56 of file symbolic_functions.c.

6.5.2.4 int Dam_gt (int *id*, double *a*, double *b*)

parameter derivative of c implementation of matlab function gt

Parameters

id	argument index for differentiation
a	value1 **Type**: double
b	value2 **Type**: double

Returns

0

Definition at line 73 of file symbolic_functions.c.

6.5.2.5 int am_le (double *a*, double *b*)

c implementation of matlab function le

Parameters

a	value1 **Type**: double
b	value2 **Type**: double

Returns

if(a <= 0) then 1 else 0
Type: int

Definition at line 85 of file symbolic_functions.c.

6.5.2.6 int Dam_le (int *id*, double *a*, double *b*)

parameter derivative of c implementation of matlab function le

Parameters

id	argument index for differentiation
a	value1 **Type**: double
b	value2 **Type**: double

Returns

0

Definition at line 102 of file symbolic_functions.c.

6.5.2.7 int am_lt (double *a*, double *b*)

c implementation of matlab function lt

Parameters

a	value1 **Type**: double

b	value2 **Type**: double

Returns

if(a $<$ 0) then 1 else 0
Type: int

Definition at line 114 of file symbolic_functions.c.

6.5.2.8 int Dam_lt (int *id*, double *a*, double *b*)

parameter derivative of c implementation of matlab function lt

Parameters

id	argument index for differentiation
a	value1 **Type**: double
b	value2 **Type**: double

Returns

0

Definition at line 131 of file symbolic_functions.c.

6.5.2.9 double am_if (int *condition*, double *truepart*, double *falsepart*)

c implementation of if function

Parameters

condition	condition that decides on the output
truepart	returnvalue if condition is true **Type**: double
falsepart	returnvalue if condition is false **Type**: double

Returns

if(condition) then truepart else falsepart
Type: int

Definition at line 144 of file symbolic_functions.c.

6.5.2.10 double Dam_if (int *id*, int *condition*, double *truepart*, double *falsepart*)

parameter derivative of c implementation of if function

Parameters

id	argument index for differentiation
condition	condition that decides on the output
truepart	returnvalue if condition is true **Type**: double

falsepart	returnvalue if condition is false **Type**: double

Returns

id==1: 0
Type: double
id==2: if(condition) then 1 else 0
Type: double
id==3: if(condition) then 0 else 1
Type: double

Definition at line 165 of file symbolic_functions.c.

6.5.2.11 int am_and (int *a*, int *b*)

c implementation of matlab function and

Parameters

a	bool1 **Type**: int
b	bool2 **Type**: int

Returns

if(a & b) then 1 else 0
Type: int

Definition at line 199 of file symbolic_functions.c.

6.5.2.12 double Dam_and (int *id*, int *a*, int *b*)

parameter derivative of c implementation of matlab function and

Parameters

id	argument index for differentiation
a	bool1 **Type**: int
b	bool2 **Type**: int

Returns

0
Type: double

Definition at line 216 of file symbolic_functions.c.

6.5.2.13 int am_or (int *a*, int *b*)

c implementation of matlab function or

Parameters

a	bool1 **Type**: int
b	bool2 **Type**: int

Returns

if(a | b) then 1 else 0
Type: int

Definition at line 228 of file symbolic_functions.c.

6.5.2.14 double Dam_or (int *id*, int *a*, int *b*)

parameter derivative of c implementation of matlab function or

Parameters

id	argument index for differentiation
a	bool1 **Type**: int
b	bool2 **Type**: int

Returns

0
Type: double

Definition at line 245 of file symbolic_functions.c.

6.5.2.15 double am_min (double *a*, double *b*)

c implementation of matlab function min

Parameters

a	value1 **Type**: double
b	value2 **Type**: double

Returns

if(a $<$ b) then a else b
Type: double

Definition at line 257 of file symbolic_functions.c.

6.5.2.16 double Dam_min (int *id*, double *a*, double *b*)

parameter derivative of c implementation of matlab function min

Parameters

id	argument index for differentiation

a	bool1 **Type**: double
b	bool2 **Type**: double

Returns

id == 1: if(a $<$ b) then 1 else 0
Type: double
id == 2: if(a $<$ b) then 0 else 1
Type: double

Definition at line 275 of file symbolic_functions.c.

6.5.2.17 double am_max (double *a*, double *b*)

c implementation of matlab function min

Parameters

a	value1 **Type**: double
b	value2 **Type**: double

Returns

if(a $>$ b) then a else b
Type: double

Definition at line 299 of file symbolic_functions.c.

6.5.2.18 double Dam_max (int *id*, double *a*, double *b*)

parameter derivative of c implementation of matlab function min

Parameters

id	argument index for differentiation
a	bool1 **Type**: double
b	bool2 **Type**: double

Returns

id == 1: if(a $>$ b) then 1 else 0
Type: double
id == 2: if(a $>$ b) then 0 else 1
Type: double

Definition at line 317 of file symbolic_functions.c.

6.5.2.19 double heaviside (double *x*)

c implementation of matlab function heaviside

Parameters

x	argument

Returns

if(x>0) then 1 else 0

Definition at line 340 of file symbolic_functions.c.

6.5.2.20 double dirac (double *x*)

c implementation of matlab function dirac

Parameters

x	argument

Returns

if(x==0) then 1 else 0

Definition at line 355 of file symbolic_functions.c.

6.5.2.21 double Ddirac (int *id,* double *x*)

derivatives of the c implementation of matlab function dirac

Parameters

id	argument index for differentiation
x	argument

Returns

0
Type: double

Definition at line 371 of file symbolic_functions.c.

6.5.2.22 double spline3 (double *t,* double *t1,* double *p1,* double *t2,* double *p2,* double *t3,* double *p3,* int *ss,* double *dudt*)

spline function with 3 nodes

Parameters

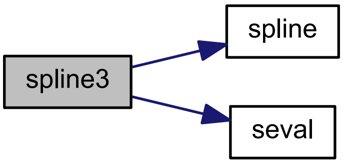
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

spline(t)

Definition at line 395 of file symbolic_functions.c.

Here is the call graph for this function:



6.5.2.23 double spline_pos3 (double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, int *ss*, double *dudt*)

positive spline function with 3 nodes

Parameters

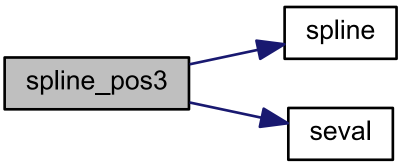
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

spline(t)

Definition at line 436 of file symbolic_functions.c.

Here is the call graph for this function:



Here is the caller graph for this function:

6.5.2.24 double spline4 (double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, int *ss*, double *dudt*)

spline function with 4 nodes

Parameters

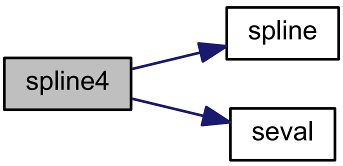
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
t4	location of node 4
p4	spline value at node 4
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

spline(t)

Definition at line 484 of file symbolic_functions.c.

Here is the call graph for this function:



6.5.2.25 double spline_pos4 (double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, int *ss*, double *dudt*)

positive spline function with 4 nodes

Parameters

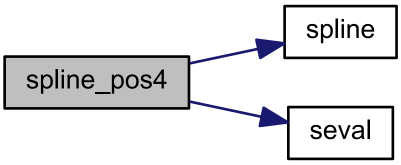
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
t4	location of node 4
p4	spline value at node 4
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

spline(t)

Definition at line 528 of file symbolic_functions.c.

Here is the call graph for this function:



Here is the caller graph for this function:

6.5.2.26 double spline5 (double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, double *t5*, double *p5*, int *ss*, double *dudt*)

spline function with 5 nodes

Parameters

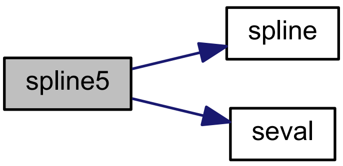
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
t4	location of node 4
p4	spline value at node 4
t5	location of node 5
p5	spline value at node 5
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

spline(t)

Definition at line 580 of file symbolic_functions.c.

Here is the call graph for this function:



6.5.2.27 double spline_pos5 (double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, double *t5*, double *p5*, int *ss*, double *dudt*)

positive spline function with 5 nodes

Parameters

t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
t4	location of node 4
p4	spline value at node 4
t5	location of node 5

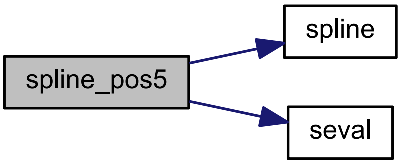
p5	spline value at node 5
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

spline(t)

Definition at line 628 of file symbolic_functions.c.

Here is the call graph for this function:



Here is the caller graph for this function:

6.5.2.28 double spline10 (double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, double *t5*, double *p5*, double *t6*, double *p6*, double *t7*, double *p7*, double *t8*, double *p8*, double *t9*, double *p9*, double *t10*, double *p10*, int *ss*, double *dudt*)

spline function with 10 nodes

Parameters

t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3

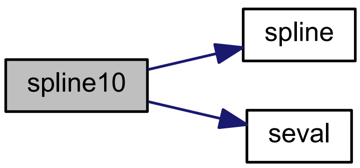
t4	location of node 4
p4	spline value at node 4
t5	location of node 5
p5	spline value at node 5
t6	location of node 6
p6	spline value at node 6
t7	location of node 7
p7	spline value at node 7
t8	location of node 8
p8	spline value at node 8
t9	location of node 9
p9	spline value at node 9
t10	location of node 10
p10	spline value at node 10
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

spline(t)

Definition at line 692 of file symbolic_functions.c.

Here is the call graph for this function:



6.5.2.29 double spline_pos10 (double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, double *t5*, double *p5*, double *t6*, double *p6*, double *t7*, double *p7*, double *t8*, double *p8*, double *t9*, double *p9*, double *t10*, double *p10*, int *ss*, double *dudt*)

positive spline function with 10 nodes

Parameters

t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3

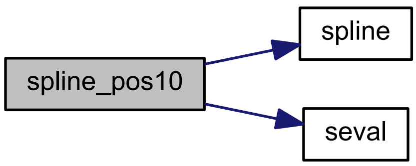
p3	spline value at node 3
t4	location of node 4
p4	spline value at node 4
t5	location of node 5
p5	spline value at node 5
t6	location of node 6
p6	spline value at node 6
t7	location of node 7
p7	spline value at node 7
t8	location of node 8
p8	spline value at node 8
t9	location of node 9
p9	spline value at node 9
t10	location of node 10
p10	spline value at node 10
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

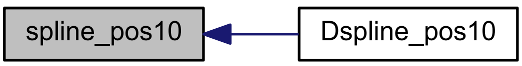
spline(t)

Definition at line 760 of file symbolic_functions.c.

Here is the call graph for this function:



Here is the caller graph for this function:



6.5.2.30 double Dspline3 (int *id*, double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, int *ss*, double *dudt*)

parameter derivative of spline function with 3 nodes

Parameters

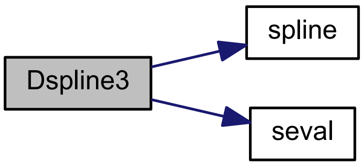
id	argument index for differentiation
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

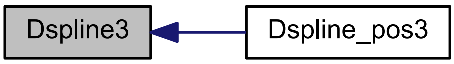
dspline(t)dp(id)

Definition at line 821 of file symbolic_functions.c.

Here is the call graph for this function:



Here is the caller graph for this function:



6.5.2.31 double Dspline_pos3 (int *id*, double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, int *ss*, double *dudt*)

parameter derivative of positive spline function with 3 nodes

Parameters

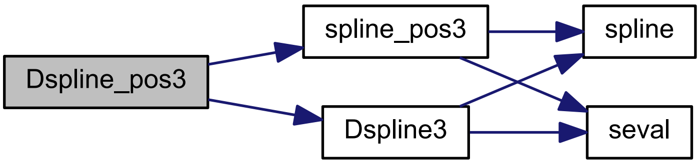
id	argument index for differentiation
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

dspline(t)dp(id)

Definition at line 866 of file symbolic_functions.c.

Here is the call graph for this function:



6.5.2.32 double Dspline4 (int *id*, double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, int *ss*, double *dudt*)

parameter derivative of spline function with 4 nodes

Parameters

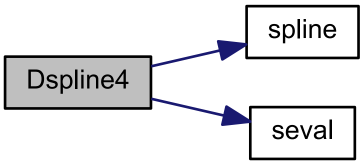
id	argument index for differentiation
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
t4	location of node 4
p4	spline value at node 4
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

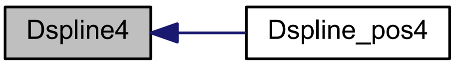
dspline(t)dp(id)

Definition at line 909 of file symbolic_functions.c.

Here is the call graph for this function:



Here is the caller graph for this function:



6.5.2.33 double Dspline_pos4 (int *id*, double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, int *ss*, double *dudt*)

parameter derivative of positive spline function with 4 nodes

Parameters

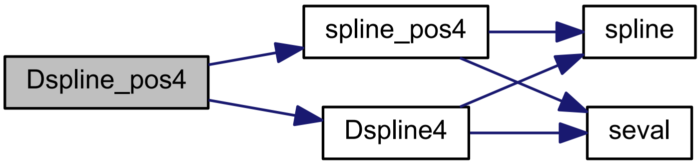
id	argument index for differentiation
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
t4	location of node 4
p4	spline value at node 4
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

dspline(t)dp(id)

Definition at line 958 of file symbolic_functions.c.

Here is the call graph for this function:



6.5.2.34 double Dspline5 (int *id*, double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, double *t5*, double *p5*, int *ss*, double *dudt*)

parameter derivative of spline function with 5 nodes

Parameters

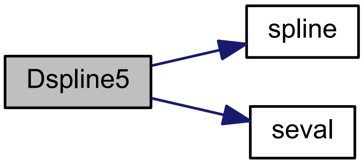
id	argument index for differentiation
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
t4	location of node 4
p4	spline value at node 4
t5	location of node 5
p5	spline value at node 5
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

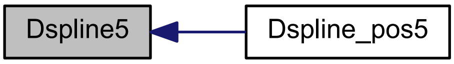
dspline(t)dp(id)

Definition at line 1003 of file symbolic_functions.c.

Here is the call graph for this function:



Here is the caller graph for this function:



6.5.2.35 double Dspline_pos5 (int *id*, double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, double *t5*, double *p5*, int *ss*, double *dudt*)

parameter derivative of positive spline function with 5 nodes

Parameters

id	argument index for differentiation
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
t4	location of node 4
p4	spline value at node 4
t5	location of node 5
p5	spline value at node 5

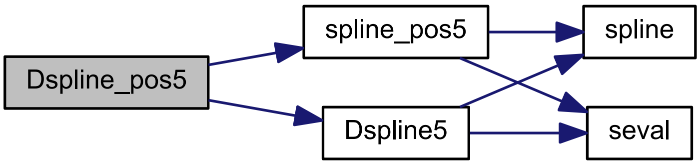
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

dspline(t)dp(id)

Definition at line 1056 of file symbolic_functions.c.

Here is the call graph for this function:



6.5.2.36 double Dspline10 (int *id*, double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, double *t5*, double *p5*, double *t6*, double *p6*, double *t7*, double *p7*, double *t8*, double *p8*, double *t9*, double *p9*, double *t10*, double *p10*, int *ss*, double *dudt*)

parameter derivative of spline function with 10 nodes

Parameters

id	argument index for differentiation
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
t4	location of node 4
p4	spline value at node 4
t5	location of node 5
p5	spline value at node 5
t6	location of node 6
p6	spline value at node 6
t7	location of node 7
p7	spline value at node 7
t8	location of node 8
p8	spline value at node 8

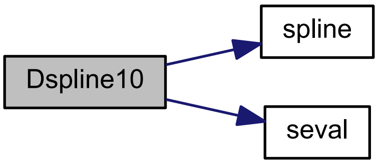
t9	location of node 9
p9	spline value at node 9
t10	location of node 10
p10	spline value at node 10
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

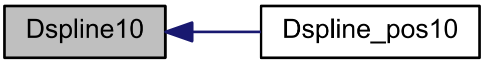
dspline(t)dp(id)

Definition at line 1112 of file symbolic_functions.c.

Here is the call graph for this function:



Here is the caller graph for this function:



6.5.2.37 double Dspline_pos10 (int *id*, double *t*, double *t1*, double *p1*, double *t2*, double *p2*, double *t3*, double *p3*, double *t4*, double *p4*, double *t5*, double *p5*, double *t6*, double *p6*, double *t7*, double *p7*, double *t8*, double *p8*, double *t9*, double *p9*, double *t10*, double *p10*, int *ss*, double *dudt*)

parameter derivative of positive spline function with 10 nodes

Parameters

id	argument index for differentiation
t	point at which the spline should be evaluated
t1	location of node 1
p1	spline value at node 1

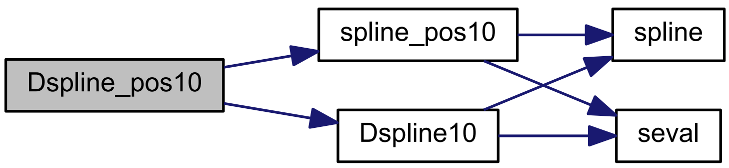
t2	location of node 2
p2	spline value at node 2
t3	location of node 3
p3	spline value at node 3
t4	location of node 4
p4	spline value at node 4
t5	location of node 5
p5	spline value at node 5
t6	location of node 6
p6	spline value at node 6
t7	location of node 7
p7	spline value at node 7
t8	location of node 8
p8	spline value at node 8
t9	location of node 9
p9	spline value at node 9
t10	location of node 10
p10	spline value at node 10
ss	flag indicating whether slope at first node should be user defined
dudt	user defined slope at first node

Returns

dspline(t)dp(id)

Definition at line 1185 of file symbolic_functions.c.

Here is the call graph for this function:



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