

DOS extraction

Generated by Doxygen 1.8.6

Fri Oct 3 2014 00:29:27

Contents

1	Index	1
1.1	Introduction	1
1.2	Dependancies	1
1.3	Compile	1
1.4	Set up the configurations	2
1.5	Run!	2
2	Namespace Index	3
2.1	Namespace List	3
3	Hierarchical Index	5
3.1	Class Hierarchy	5
4	Class Index	7
4.1	Class List	7
5	File Index	9
5.1	File List	9
6	Namespace Documentation	11
6.1	constants Namespace Reference	11
6.1.1	Detailed Description	11
6.2	numerics Namespace Reference	11
6.2.1	Detailed Description	12
6.2.2	Function Documentation	12
6.2.2.1	sort	12
6.2.2.2	sort_pair	12
6.2.2.3	trapz	13
6.2.2.4	trapz	13
6.2.2.5	deriv	13
6.2.2.6	interp1	13
6.2.2.7	interp1	14
6.2.2.8	error_L2	14

6.3	utility Namespace Reference	14
6.3.1	Detailed Description	15
6.3.2	Function Documentation	15
6.3.2.1	full_path	15
6.3.2.2	print_block	15
6.3.2.3	print_done	15
7	Class Documentation	17
7.1	Bim1D Class Reference	17
7.1.1	Detailed Description	18
7.1.2	Constructor & Destructor Documentation	18
7.1.2.1	Bim1D	18
7.1.3	Member Function Documentation	18
7.1.3.1	log_mean	18
7.1.3.2	bernoulli	18
7.1.3.3	assembleAdvDiff	19
7.1.3.4	assembleStiff	19
7.1.3.5	assembleMass	19
7.2	Charge Class Reference	19
7.2.1	Detailed Description	20
7.2.2	Constructor & Destructor Documentation	20
7.2.2.1	Charge	20
7.2.3	Member Function Documentation	20
7.2.3.1	charge	20
7.2.3.2	dcharge	21
7.3	ChargeFactory Class Reference	21
7.3.1	Detailed Description	21
7.3.2	Member Function Documentation	22
7.3.2.1	BuildCharge	22
7.4	CsvParser Class Reference	22
7.4.1	Detailed Description	23
7.4.2	Constructor & Destructor Documentation	23
7.4.2.1	CsvParser	23
7.4.3	Member Function Documentation	23
7.4.3.1	importRow	23
7.4.3.2	importRows	24
7.4.3.3	importFirstRows	25
7.4.3.4	importCol	25
7.4.3.5	importCols	25
7.4.3.6	importFirstCols	25

7.4.3.7	importCell	26
7.4.3.8	importAll	26
7.5	DosModel Class Reference	26
7.5.1	Detailed Description	27
7.5.2	Constructor & Destructor Documentation	27
7.5.2.1	DosModel	27
7.5.3	Member Function Documentation	27
7.5.3.1	simulate	27
7.5.3.2	post_process	28
7.5.3.3	gnuplot_commands	29
7.5.3.4	save_plot	29
7.6	ExponentialCharge Class Reference	29
7.6.1	Detailed Description	30
7.6.2	Constructor & Destructor Documentation	30
7.6.2.1	ExponentialCharge	30
7.6.3	Member Function Documentation	31
7.6.3.1	charge	31
7.6.3.2	dcharge	32
7.6.3.3	n_approx	32
7.6.3.4	dn_approx	32
7.7	ExponentialChargeFactory Class Reference	33
7.7.1	Detailed Description	33
7.7.2	Member Function Documentation	33
7.7.2.1	BuildCharge	33
7.8	GaussHermiteRule Class Reference	34
7.8.1	Detailed Description	34
7.8.2	Constructor & Destructor Documentation	34
7.8.2.1	GaussHermiteRule	34
7.8.3	Member Function Documentation	35
7.8.3.1	apply	35
7.9	GaussHermiteRuleFactory Class Reference	35
7.9.1	Detailed Description	35
7.9.2	Member Function Documentation	36
7.9.2.1	BuildRule	36
7.10	GaussianCharge Class Reference	37
7.10.1	Detailed Description	38
7.10.2	Constructor & Destructor Documentation	38
7.10.2.1	GaussianCharge	38
7.10.3	Member Function Documentation	38
7.10.3.1	charge	38

7.10.3.2	dcharge	38
7.10.3.3	n_approx	39
7.10.3.4	dn_approx	40
7.11	GaussianChargeFactory Class Reference	40
7.11.1	Detailed Description	41
7.11.2	Member Function Documentation	41
7.11.2.1	BuildCharge	41
7.12	GaussLaguerreRule Class Reference	41
7.12.1	Detailed Description	42
7.12.2	Constructor & Destructor Documentation	42
7.12.2.1	GaussLaguerreRule	42
7.12.3	Member Function Documentation	42
7.12.3.1	apply	42
7.12.3.2	log_gamma	42
7.13	GaussLaguerreRuleFactory Class Reference	43
7.13.1	Detailed Description	43
7.13.2	Member Function Documentation	43
7.13.2.1	BuildRule	43
7.14	NonLinearPoisson1D Class Reference	44
7.14.1	Detailed Description	45
7.14.2	Constructor & Destructor Documentation	45
7.14.2.1	NonLinearPoisson1D	45
7.14.3	Member Function Documentation	45
7.14.3.1	apply	45
7.14.3.2	computeJac	45
7.15	ParamList Class Reference	46
7.15.1	Detailed Description	48
7.15.2	Constructor & Destructor Documentation	48
7.15.2.1	ParamList	48
7.16	PdeSolver1D Class Reference	48
7.16.1	Detailed Description	49
7.16.2	Constructor & Destructor Documentation	49
7.16.2.1	PdeSolver1D	49
7.16.3	Member Function Documentation	50
7.16.3.1	assembleAdvDiff	50
7.16.3.2	assembleStiff	51
7.16.3.3	assembleMass	51
7.17	QuadratureRule Class Reference	51
7.17.1	Detailed Description	52
7.17.2	Constructor & Destructor Documentation	52

7.17.2.1	QuadratureRule	52
7.17.3	Member Function Documentation	53
7.17.3.1	apply	53
7.18	QuadratureRuleFactory Class Reference	53
7.18.1	Detailed Description	53
7.18.2	Member Function Documentation	53
7.18.2.1	BuildRule	54
8	File Documentation	57
8.1	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/charge.cc File Reference	57
8.1.1	Detailed Description	57
8.2	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/charge.h File Reference	57
8.2.1	Detailed Description	58
8.3	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/csvParser.cc File Reference	58
8.3.1	Detailed Description	58
8.4	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/csvParser.h File Reference	58
8.4.1	Detailed Description	58
8.5	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/dosModel.cc File Reference	59
8.5.1	Detailed Description	59
8.6	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/dosModel.h File Reference	59
8.6.1	Detailed Description	59
8.7	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.cc File Reference	60
8.7.1	Detailed Description	60
8.8	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.h File Reference	60
8.8.1	Detailed Description	61
8.9	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/numerics.cc File Reference	61
8.9.1	Detailed Description	61
8.10	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/numerics.h File Reference	61
8.10.1	Detailed Description	62
8.11	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/paramList.cc File Reference	62
8.11.1	Detailed Description	62
8.12	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/paramList.h File Reference	62
8.12.1	Detailed Description	63
8.13	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/physicalConstants.h File Reference	63
8.13.1	Detailed Description	64
8.14	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadratureRule.cc File Reference	64
8.14.1	Detailed Description	64
8.15	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadratureRule.h File Reference	64
8.15.1	Detailed Description	65
8.16	/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/solvers.cc File Reference	65

8.16.1 Detailed Description	65
8.17 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/solvers.h File Reference	65
8.17.1 Detailed Description	66
8.18 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/typedefs.cc File Reference	66
8.18.1 Detailed Description	66
8.19 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/typedefs.h File Reference	66
8.19.1 Detailed Description	68
8.19.2 Typedef Documentation	68
8.19.2.1 VectorX	68
8.19.2.2 VectorXpair	68
8.20 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/test/simulate_dos.cc File Reference	68
8.20.1 Detailed Description	68
Index	70

Chapter 1

Index

1.1 Introduction

This program allows to extract the Density of States, assessed by mean capacitance-voltage measurements, in an organic semiconductor device. Simulated values are fitted to experimental data.

Source and header files are written in C++11 language.

The software is intended to be used on a Unix-like operating system.

1.2 Dependancies

The program requires the following libraries to be installed on your system:

- **CMake**, a cross-platform configuration tool (version 2.8 or above);
- **Eigen**, to handle with matrices, vectors and linear algebra;
- **Gnuplot**, a graphical utility to generate plots;
- **Boost**, a C++ library used by the **Gnuplot** interface to C++;
- **OpenMP**, for parallel computing (recommended but not compulsory);
- **Doxygen**, a documentation generator (not compulsory).

It also uses the following packages, provided in the *include/* folder:

- **GetPot**, to parse command-line and configuration files;
- **gnuplot-iostream**, the C++ interface for **Gnuplot**.

1.3 Compile

In order to generate a test executable, simply execute one of these commands in a terminal pointing to the root directory of this package:

```
$ mkdir build
$ cd build
$ cmake ..
$ make
```

or, if you want the compiler to produce also debugging informations:

```
$ mkdir build
$ cd build
$ cmake .. -DDEBUG_MODE=ON
$ make
```

You can specify the name of the test source to be compiled (without extension, for example: *simulate_dos*) by editing the variable **EXEC**, defined in the *CMakeLists.txt* file.

Repeat these instructions for each test you want to compile.

The following command will generate this documentation under the *doc/* folder (or the one specified in *CMakeLists.txt*):

```
$ make doc
```

1.4 Set up the configurations

Note

The default configuration directory is *config/*.

Before you can run an executable, you have to set up the configuration file (default: *config.pot*). Within it you can find a list of parameters, each of which is commented out to explain what modifying it will entail.

Particularly, the variables *input_params* and *input_experim* can be set, i.e. the filenames where to find input fitting parameters and experimental data respectively. It's recommended (but not compulsory) to put these files in the same directory as the configuration file (otherwise you can specify a relative or absolute path to them).

You can create multiple configuration files, each with different parameter values: the one you aim to use can be specified in the command-line before running.

1.5 Run!

Executables are placed under the *bin/* directory (or the one specified in *CMakeLists.txt*).

To run by using the default configuration filename (*config.pot*) simply move to the *bin/* directory and execute:

```
$ ./test_filename
```

To specify a different configuration file previously saved in the configuration directory:

```
$ ./test_filename -f configuration_filename
```

or:

```
$ ./test_filename --file configuration_filename
```

The variable *configuration_filename* should **not** contain the path.

Warning

Furthermore, if you run the program from a different folder than *bin/* or if you chose a different configuration directory, you have to manually specify the **full** path to the configuration directory (either absolute or relative to the current directory) by using:

```
$ ./test_filename -d configuration_directory
```

or:

```
$ ./test_filename --directory configuration_directory
```

Once complete, you can find the results of the simulation(s) in the output directory specified in the configuration file (default: *output*) under *bin/*.

Chapter 2

Namespace Index

2.1 Namespace List

Here is a list of all documented namespaces with brief descriptions:

constants	Numerical constants	11
numerics	Namespace for generic numeric algorithms	11
utility	Namespace for utilities and auxiliary functions	14

Chapter 3

Hierarchical Index

3.1 Class Hierarchy

This inheritance list is sorted roughly, but not completely, alphabetically:

Charge	19
ExponentialCharge	29
GaussianCharge	37
ChargeFactory	21
ExponentialChargeFactory	33
GaussianChargeFactory	40
CsvParser	22
DosModel	26
NonLinearPoisson1D	44
ParamList	46
PdeSolver1D	48
Bim1D	17
QuadratureRule	51
GaussHermiteRule	34
GaussLaguerreRule	41
QuadratureRuleFactory	53
GaussHermiteRuleFactory	35
GaussLaguerreRuleFactory	43

Chapter 4

Class Index

4.1 Class List

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

Bim1D	Class derived from PdeSolver1D , providing a finite volume Box Integration Method (BIM) solver	17
Charge	Abstract class providing methods to calculate total electric charge (the rhs in the Poisson equation)	19
ChargeFactory	Abstract factory to handle at runtime a constitutive relation for the Density of States	21
CsvParser	Class providing methods to read numeric content from a .csv file and to store it in Eigen matrices or vectors	22
DosModel	Class providing methods to process a simulation to extract the Density of States starting from a parameter list	26
ExponentialCharge	Class derived from Charge , under the hypothesis that Density of States is a single exponential	29
ExponentialChargeFactory	Concrete factory to handle a single exponential constitutive relation	33
GaussHermiteRule	Class derived from QuadratureRule providing the Gauss-Hermite quadrature rule	34
GaussHermiteRuleFactory	Concrete factory to handle a Gauss-Hermite quadrature rule	35
GaussianCharge	Class derived from Charge , under the hypothesis that Density of States is a combination of gaussians	37
GaussianChargeFactory	Concrete factory to handle a multiple gaussians constitutive relation	40
GaussLaguerreRule	Class derived from QuadratureRule providing the Gauss-Laguerre quadrature rule	41
GaussLaguerreRuleFactory	Concrete factory to handle a Gauss-Laguerre quadrature rule	43
NonLinearPoisson1D	Provide a solver for a non-linear Poisson equation	44
ParamList	Class providing methods to handle a list of parameters	46
PdeSolver1D	Abstract class providing methods to assemble matrices to solve one-dimensional PDEs	48
QuadratureRule	Abstract class providing a quadrature rule	51

[QuadratureRuleFactory](#)

Abstract factory to handle at runtime a quadrature rule [53](#)

Chapter 5

File Index

5.1 File List

Here is a list of all documented files with brief descriptions:

/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ charge.cc	57
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ charge.h	
Classes for computing total electric charge	57
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ csvParser.cc	58
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ csvParser.h	
Tools to store content from a .csv file in matrices or vectors	58
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ dosModel.cc	59
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ dosModel.h	
Mathematical model for Density of States extraction	59
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ factory.cc	60
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ factory.h	
Abstract factories for the DOS constitutive relation and for the quadrature rule	60
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ numerics.cc	61
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ numerics.h	
Generic numeric algorithms	61
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ paramList.cc	62
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ paramList.h	
List of simulation parameters	62
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ physicalConstants.h	
Physical constants	63
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ quadratureRule.cc	64
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ quadratureRule.h	
Quadrature rules	64
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ solvers.cc	65
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ solvers.h	
Generic solvers for PDEs	65
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ typedefs.cc	66
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/ typedefs.h	
Typedefs and utility functions	66
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/test/ simulate_dos.cc	
A test file	68

Chapter 6

Namespace Documentation

6.1 constants Namespace Reference

Numerical constants.

Variables

- const [Real Q](#) = 1.602176530000000e-19
Electron charge [C].
- const [Real Q2](#) = [Q](#) * [Q](#)
Electron charge squared [C²].
- const [Real K_B](#) = 1.380650500000000e-23
Boltzmann's constant [J · K⁻¹].
- const [Real EPS0](#) = 8.854187817e-12
Vacuum electrical permittivity [C · V⁻¹ · m⁻¹].
- const [Real T](#) = 300
Reference temperature [K].
- const [Real V_TH](#) = [K_B](#) * [T](#) / [Q](#)
Threshold voltage [V].
- const [Index PARAMS_NO](#) = 24
Number of parameters required in input file.
- const [Real PI](#) = [M_PI](#)
 π .
- const [Real SQRT_PI](#) = std::sqrt([PI](#))
 $\sqrt{\pi}$.
- const [Real PI_M4](#) = 0.7511255444649425
 $\pi^{-\frac{1}{4}}$.
- const [Real SQRT_2](#) = std::sqrt(2)
 $\sqrt{2}$.

6.1.1 Detailed Description

Numerical constants.

6.2 numerics Namespace Reference

Namespace for generic numeric algorithms.

Functions

- `template<typename ScalarType >
VectorX< ScalarType > sort (const VectorX< ScalarType > &vector)`
Function to sort [Eigen](#) vectors.
- `template<typename ScalarType >
VectorXpair< ScalarType > sort_pair (const VectorX< ScalarType > &vector)`
Function to sort [Eigen](#) vectors, keeping track of indexes.
- `Real trapz (const VectorXr &x, const VectorXr &y)`
Function to compute approximate integral of y with spacing increment specified by x, using trapezoidal rule.
- `Real trapz (const VectorXr &y)`
Compute the approximate integral of y with unit spacing, using trapezoidal rule.
- `VectorXr deriv (const VectorXr &, const VectorXr &)`
Compute the numeric derivative: $\frac{dy}{dx}$.
- `Real interp1 (const VectorXr &, const VectorXr &, const Real &)`
Linear 1D interpolation. Interpolate y, defined at points x, at the point xNew.
- `VectorXr interp1 (const VectorXr &, const VectorXr &, const VectorXr &)`
Linear 1D interpolation. Interpolate y, defined at points x, at the points xNew.
- `Real error_L2 (const VectorXr &, const VectorXr &, const VectorXr &, const Real &)`
Compute the L^2 -norm error between simulated and interpolated values, using trapz.

6.2.1 Detailed Description

Namespace for generic numeric algorithms.

6.2.2 Function Documentation

6.2.2.1 `VectorX< ScalarType > sort (const VectorX< ScalarType > & vector)`

Function to sort [Eigen](#) vectors.

Template Parameters

<i>ScalarType</i>	: the scalar type.
-------------------	--------------------

Parameters

<i>in</i>	<i>vector</i>	: the vector to be sorted.
-----------	---------------	----------------------------

Returns

the sorted vector.

Definition at line 98 of file numerics.h.

6.2.2.2 `VectorXpair< ScalarType > sort_pair (const VectorX< ScalarType > & vector)`

Function to sort [Eigen](#) vectors, keeping track of indexes.

Template Parameters

<i>ScalarType</i>	: the scalar type.
-------------------	--------------------

Parameters

in	<i>vector</i>	: the vector to be sorted.
----	---------------	----------------------------

Returns

an [Eigen](#) vector of pairs: (sorted value, corresponding index in the unsorted vector).

Definition at line 107 of file numerics.h.

6.2.2.3 Real trapz (const VectorXr & x, const VectorXr & y)

Function to compute approximate integral of *y* with spacing increment specified by *x*, using trapezoidal rule.

Parameters

in	<i>x</i>	: the vector of the discrete domain;
in	<i>y</i>	: the vector of values to integrate.

Returns

the approximate integral value.

Definition at line 12 of file numerics.cc.

6.2.2.4 Real trapz (const VectorXr & y)

Compute the approximate integral of *y* with unit spacing, using trapezoidal rule.

Parameters

in	<i>y</i>	: the vector of values to integrate.
----	----------	--------------------------------------

Returns

the approximate integral value.

Definition at line 28 of file numerics.cc.

6.2.2.5 VectorXr deriv (const VectorXr & y, const VectorXr & x)

Compute the numeric derivative: $\frac{dy}{dx}$.

Parameters

in	<i>y</i>	: the vector of values to differentiate;
in	<i>x</i>	: the vector of the discrete domain.

Returns

a vector of the same length as *y* containing the approximate derivative.

Definition at line 33 of file numerics.cc.

6.2.2.6 Real interp1 (const VectorXr & x, const VectorXr & y, const Real & xNew)

Linear 1D interpolation. Interpolate *y*, defined at points *x*, at the point *xNew*.

Parameters

in	<i>y</i>	: the vector of values to interpolate;
in	<i>x</i>	: the vector of the discrete domain;
in	<i>xNew</i>	: the point to interpolate at.

Returns

a scalar containing the interpolated value.

Definition at line 53 of file numerics.cc.

6.2.2.7 VectorXr interp1 (const VectorXr & x, const VectorXr & y, const VectorXr & xNew)

Linear 1D interpolation. Interpolate *y*, defined at points *x*, at the points *xNew*.

Parameters

in	<i>y</i>	: the vector of values to interpolate;
in	<i>x</i>	: the vector of the discrete domain;
in	<i>xNew</i>	: the vector of points to interpolate at.

Returns

a vector of the same length as *xNew* containing the interpolated values.

Definition at line 74 of file numerics.cc.

6.2.2.8 Real error_L2 (const VectorXr & interp, const VectorXr & simulated, const VectorXr & V, const Real & V_shift)

Compute the L^2 -norm error between simulated and interpolated values, using *trapz*.

Parameters

in	<i>interp</i>	: the interpolated values;
in	<i>simulated</i>	: the simulated values;
in	<i>V</i>	: the vector of the electric potential;
in	<i>V_shift</i>	: shift to the electric potential.

Returns

the value of the L^2 -norm error.

Definition at line 89 of file numerics.cc.

6.3 utility Namespace Reference

Namespace for utilities and auxiliary functions.

Functions

- std::string [full_path](#) (const std::string &, const std::string &)
Auxiliary function to return the full path to a file.
- void [print_block](#) (const char *, std::ostream &=std::cout)
Auxiliary function to print a string inside a block.
- void [print_done](#) (std::ostream &=std::cout)
Auxiliary function to print a "DONE!" string.

6.3.1 Detailed Description

Namespace for utilities and auxiliary functions.

6.3.2 Function Documentation

6.3.2.1 `std::string full_path (const std::string & filename, const std::string & relative_directory)`

Auxiliary function to return the full path to a file.

Parameters

in	<i>filename</i>	: the filename;
in	<i>relative_ - directory</i>	: the directory for a relative path.

Returns

the variable *filename*, if it contains an absolute path; otherwise returns the concatenation of *relative_directory* and *filename* (i.e. the relative path to *filename*).

Definition at line 12 of file typedefs.cc.

6.3.2.2 `void print_block (const char * string, std::ostream & os = std::cout)`

Auxiliary function to print a string inside a block.

Parameters

in	<i>string</i>	: the string to print;
out	<i>os</i>	: output stream.

Definition at line 17 of file typedefs.cc.

6.3.2.3 `void print_done (std::ostream & os = std::cout)`

Auxiliary function to print a "DONE!" string.

Parameters

out	<i>os</i>	: output stream.
-----	-----------	------------------

Definition at line 42 of file typedefs.cc.

Chapter 7

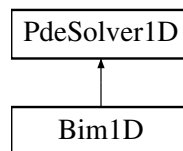
Class Documentation

7.1 Bim1D Class Reference

Class derived from [PdeSolver1D](#), providing a finite volume Box Integration Method (BIM) solver.

```
#include <solvers.h>
```

Inheritance diagram for Bim1D:



Public Member Functions

- [Bim1D](#) ()=delete
Default constructor (deleted since it is required to specify the mesh).
- [Bim1D](#) ([VectorXr](#) &)
Constructor.
- virtual [~Bim1D](#) ()=default
Destructor (defaulted).
- virtual void [assembleAdvDiff](#) (const [VectorXr](#) &, const [VectorXr](#) &, const [VectorXr](#) &, const [VectorXr](#) &) override
Assemble the matrix for an advection-diffusion term.
- virtual void [assembleStiff](#) (const [VectorXr](#) &, const [VectorXr](#) &) override
Assemble the matrix for a diffusion term.
- virtual void [assembleMass](#) (const [VectorXr](#) &, const [VectorXr](#) &) override
Assemble the matrix for a reaction term.

Static Public Member Functions

- static [VectorXr](#) [log_mean](#) (const [VectorXr](#) &, const [VectorXr](#) &)
Compute the element-wise logarithmic mean of two vectors.
- static std::pair< [VectorXr](#),
[VectorXr](#) > [bernoulli](#) (const [VectorXr](#) &)
Compute the values of the Bernoulli function.

Additional Inherited Members

7.1.1 Detailed Description

Class derived from [PdeSolver1D](#), providing a finite volume Box Integration Method (BIM) solver.

Matrices are held in a sparse format.

Definition at line 112 of file solvers.h.

7.1.2 Constructor & Destructor Documentation

7.1.2.1 Bim1D (VectorXr & mesh)

Constructor.

Parameters

in	mesh	: the mesh coordinates.
----	------	-------------------------

Definition at line 15 of file solvers.cc.

7.1.3 Member Function Documentation

7.1.3.1 VectorXr log_mean (const VectorXr & x1, const VectorXr & x2) [static]

Compute the element-wise logarithmic mean of two vectors.

$$M_{log}(x_1, x_2) = \frac{x_2 - x_1}{\log x_2 - \log x_1} = \frac{x_2 - x_1}{\log \left(\frac{x_2}{x_1} \right)}.$$

Parameters

in	x1	: the first vector;
in	x2	: the second vector.

Returns

the vector of the logarithmic means.

Definition at line 18 of file solvers.cc.

7.1.3.2 std::pair< VectorXr, VectorXr > bernoulli (const VectorXr & x) [static]

Compute the values of the Bernoulli function.

$$\mathfrak{B}(x) = \frac{x}{e^x - 1}.$$

Parameters

in	x	: the vector of the values to compute the Bernoulli function at.
----	---	--

Returns

the pair $(\mathfrak{B}(x), \mathfrak{B}(-x))$.

Definition at line 49 of file solvers.cc.

7.1.3.3 `void assembleAdvDiff (const VectorXr & alpha, const VectorXr & gamma, const VectorXr & eta, const VectorXr & beta) [override],[virtual]`

Assemble the matrix for an advection-diffusion term.

Build the Scharfetter-Gummel stabilized stiffness matrix for: $-\nabla \cdot (\alpha \cdot \gamma (\eta \nabla u - \beta u)) = f$.

Parameters

in	<i>alpha</i>	: α , an element-wise constant function;
in	<i>gamma</i>	: γ , an element-wise linear function;
in	<i>eta</i>	: η , an element-wise linear function;
in	<i>beta</i>	: β , an element-wise constant function.

Implements [PdeSolver1D](#).

Definition at line 108 of file solvers.cc.

7.1.3.4 `void assembleStiff (const VectorXr & eps, const VectorXr & kappa) [override],[virtual]`

Assemble the matrix for a diffusion term.

Build the standard finite element stiffness matrix for the diffusion problem: $-\nabla \cdot (\varepsilon \cdot \kappa \nabla u) = f$.

Parameters

in	<i>eps</i>	: ε , an element-wise constant function;
in	<i>kappa</i>	: κ , an element-wise linear function.

Implements [PdeSolver1D](#).

Definition at line 168 of file solvers.cc.

7.1.3.5 `void assembleMass (const VectorXr & delta, const VectorXr & zeta) [override],[virtual]`

Assemble the matrix for a reaction term.

Build the lumped finite element mass matrix for the reaction problem: $\delta \cdot \zeta u = f$.

Parameters

in	<i>delta</i>	: δ , an element-wise constant function;
in	<i>zeta</i>	: ζ , an element-wise linear function.

Implements [PdeSolver1D](#).

Definition at line 177 of file solvers.cc.

The documentation for this class was generated from the following files:

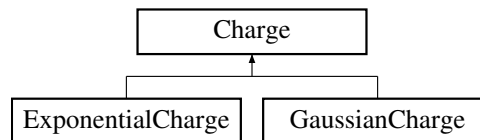
- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[solvers.h](#)
- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[solvers.cc](#)

7.2 Charge Class Reference

Abstract class providing methods to calculate total electric charge (the rhs in the Poisson equation).

```
#include <charge.h>
```

Inheritance diagram for Charge:



Public Member Functions

- `Charge ()=delete`
Default constructor (deleted since it is required to specify a [ParamList](#) and a [QuadratureRule](#)).
- `Charge (const ParamList &, const QuadratureRule &)`
Constructor.
- `virtual ~Charge ()=default`
Destructor (defaulted).
- `virtual VectorXr charge (const VectorXr &phi)=0`
Compute the total charge.
- `virtual VectorXr dcharge (const VectorXr &phi)=0`
Compute the derivative of the total charge with respect to the electric potential.

Protected Attributes

- `const ParamList & params_`
Parameter list handler.
- `const QuadratureRule & rule_`
Quadrature rule handler.

7.2.1 Detailed Description

Abstract class providing methods to calculate total electric charge (the rhs in the Poisson equation).

Definition at line 25 of file charge.h.

7.2.2 Constructor & Destructor Documentation

7.2.2.1 `Charge (const ParamList & params, const QuadratureRule & rule)`

Constructor.

Parameters

in	<i>params</i>	: the list of simulation parameters;
in	<i>rule</i>	: a quadrature rule.

Definition at line 14 of file charge.cc.

7.2.3 Member Function Documentation

7.2.3.1 `virtual VectorXr charge (const VectorXr & phi) [pure virtual]`

Compute the total charge.

Parameters

<code>in</code>	<code>phi</code>	: the electric potential φ .
-----------------	------------------	--------------------------------------

Returns

the total charge $q[C]$.

Implemented in [ExponentialCharge](#), and [GaussianCharge](#).

7.2.3.2 virtual VectorXr dcharge (const VectorXr & phi) [pure virtual]

Compute the derivative of the total charge with respect to the electric potential.

Parameters

<code>in</code>	<code>phi</code>	: the electric potential φ .
-----------------	------------------	--------------------------------------

Returns

the derivative: $\frac{dq}{d\varphi} [C \cdot V^{-1}]$.

Implemented in [ExponentialCharge](#), and [GaussianCharge](#).

The documentation for this class was generated from the following files:

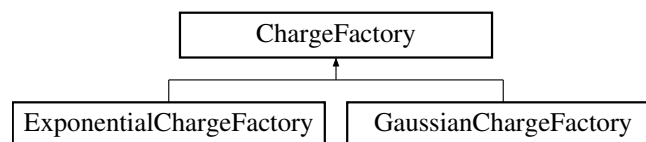
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/charge.h](#)
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/charge.cc](#)

7.3 ChargeFactory Class Reference

Abstract factory to handle at runtime a constitutive relation for the Density of States.

```
#include <factory.h>
```

Inheritance diagram for ChargeFactory:



Public Member Functions

- [ChargeFactory](#) ()=default
Default constructor (defaulted).
- virtual [~ChargeFactory](#) ()=default
Destructor (defaulted).
- virtual [Charge](#) * [BuildCharge](#) (const [ParamList](#) ¶ms, const [QuadratureRule](#) &rule)=0
Method to build an abstract [Charge](#) object.

7.3.1 Detailed Description

Abstract factory to handle at runtime a constitutive relation for the Density of States.

Definition at line 25 of file `factory.h`.

7.3.2 Member Function Documentation

7.3.2.1 `virtual Charge* BuildCharge (const ParamList & params, const QuadratureRule & rule) [pure virtual]`

Method to build an abstract [Charge](#) object.

Parameters

in	<i>params</i>	: the list of simulation parameters;
in	<i>rule</i>	: a quadrature rule.

Returns

a pointer to [Charge](#).

Implemented in [ExponentialChargeFactory](#), and [GaussianChargeFactory](#).

The documentation for this class was generated from the following file:

- `/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.h`

7.4 CsvParser Class Reference

Class providing methods to read **numeric** content from a .csv file and to store it in [Eigen](#) matrices or vectors.

```
#include <csvParser.h>
```

Public Member Functions

- [CsvParser](#) ()=delete
Default constructor (deleted since it is required to specify at least a filename).
- [CsvParser](#) (const std::string &, const bool &=true)
Constructor: load the input file and check its compatibility with the code.
- virtual [~CsvParser](#) ()
Destructor: close the input file.
- [RowVectorXr importRow](#) (const [Index](#) &)
Method to import a row from the input file.
- [MatrixXr importRows](#) (const std::initializer_list< [Index](#) > &)
Method to import multiple rows from the input file.
- [MatrixXr importFirstRows](#) (const [Index](#) &)
Method to import the first nRows rows from the input file.
- [VectorXr importCol](#) (const [Index](#) &)
Method to import a column from the input file.
- [MatrixXr importCols](#) (const std::initializer_list< [Index](#) > &)
Method to import multiple columns from the input file.
- [MatrixXr importFirstCols](#) (const [Index](#) &)
Method to import the first nCols columns from the input file.
- [Real importCell](#) (const [Index](#) &, const [Index](#) &)
Method to import a single cell from the input file.
- [MatrixXr importAll](#) ()
Method to import the whole input file.

Getter methods

- const [Index](#) & **nRows** () const
- const [Index](#) & **nCols** () const

Private Member Functions

- void [reset](#) ()
Reset all the flags for input_ and go back to the beginning of file (possibly by ignoring headers).

Private Attributes

- bool [hasHeaders_](#)
bool to determine if first row contains headers or not.
- [Index](#) [nRows_](#)
Number of rows in the input file.
- [Index](#) [nCols_](#)
Number of columns in the input file.
- [std::ifstream](#) [input_](#)
Input stream to input_filename.
- [std::string](#) [line_](#)
Auxiliary variable to store currently processed line.
- char [separator_](#)
The separator character detected.

7.4.1 Detailed Description

Class providing methods to read **numeric** content from a .csv file and to store it in [Eigen](#) matrices or vectors.
Definition at line 29 of file csvParser.h.

7.4.2 Constructor & Destructor Documentation

7.4.2.1 CsvParser (const [std::string](#) & *input_filename*, const bool & *hasHeaders* = `true`)

Constructor: load the input file and check its compatibility with the code.

Parameters

in	<i>input_filename</i>	: the name of the input file;
in	<i>hasHeaders</i>	: bool to specify if first row contains headers or not; if true , first row is always ignored.

Definition at line 19 of file csvParser.cc.

7.4.3 Member Function Documentation

7.4.3.1 RowVectorXr importRow (const [Index](#) & *index*)

Method to import a row from the input file.

Parameters

in	<i>index</i>	: the row index.
--------------------	--------------	------------------

Returns

a row vector containing the content read.

Definition at line 90 of file csvParser.cc.

7.4.3.2 **MatrixXr** importRows (const std::initializer_list< **Index** > & *indexes*)

Method to import multiple rows from the input file.

Parameters

<i>in</i>	<i>indexes</i>	: initializer list containing the row indexes (e.g. something like {1, 3, 4}).
-----------	----------------	--

Returns

a matrix containing the content read (row by row).

Definition at line 121 of file csvParser.cc.

7.4.3.3 MatrixXr importFirstRows (const Index & nRows)

Method to import the first *nRows* rows from the input file.

Parameters

<i>in</i>	<i>nRows</i>	: the number of rows to import.
-----------	--------------	---------------------------------

Returns

a matrix containing the content read (row by row).

Definition at line 138 of file csvParser.cc.

7.4.3.4 VectorXr importCol (const Index & index)

Method to import a column from the input file.

Parameters

<i>in</i>	<i>index</i>	: the column index.
-----------	--------------	---------------------

Returns

a column vector containing the content read.

Definition at line 152 of file csvParser.cc.

7.4.3.5 MatrixXr importCols (const std::initializer_list< Index > & indexes)

Method to import multiple columns from the input file.

Parameters

<i>in</i>	<i>indexes</i>	: initializer list containing the column indexes (e.g. something like {1, 3, 4}).
-----------	----------------	---

Returns

a matrix containing the content read (column by column).

Definition at line 179 of file csvParser.cc.

7.4.3.6 MatrixXr importFirstCols (const Index & nCols)

Method to import the first *nCols* columns from the input file.

Parameters

<code>in</code>	<code>nCols</code>	: the number of columns to import.
-----------------	--------------------	------------------------------------

Returns

a matrix containing the content read (column by column).

Definition at line 196 of file csvParser.cc.

7.4.3.7 Real importCell (const Index & rowIndex, const Index & colIndex)

Method to import a single cell from the input file.

Parameters

<code>in</code>	<code>rowIndex</code>	: the cell row index.
<code>in</code>	<code>colIndex</code>	: the cell column index.

Returns

a scalar containing the value read.

Definition at line 210 of file csvParser.cc.

7.4.3.8 MatrixXr importAll ()

Method to import the whole input file.

Returns

a matrix containing the content read (cell by cell).

Definition at line 218 of file csvParser.cc.

The documentation for this class was generated from the following files:

- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[csvParser.h](#)
- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[csvParser.cc](#)

7.5 DosModel Class Reference

Class providing methods to process a simulation to extract the Density of States starting from a parameter list.

```
#include <dosModel.h>
```

Public Member Functions

- [DosModel](#) ()
Default constructor.
- [DosModel](#) (const [ParamList](#) &)
Explicit conversion constructor.
- virtual [~DosModel](#) ()=default
Destructor (defaulted).
- const [ParamList](#) & [params](#) () const

Getter method.

- void [simulate](#) (const GetPot &, const std::string &, const std::string &, const std::string &, const std::string &) const

Perform the simulation.

- void [post_process](#) (const GetPot &, const std::string &, std::ostream &, std::ostream &, const [VectorXr](#) &, const [VectorXr](#) &, const [VectorXr](#) &) const

Perform post-processing.

- void [gnuplot_commands](#) (const std::string &, std::ostream &) const

Defines commands to generate [Gnuplot](#) output files.

- void [save_plot](#) (const std::string &, const std::string &, const std::string &, const std::string &) const

Save the [Gnuplot](#) output files.

Private Attributes

- bool [initialized_](#)

bool to determine if [DosModel](#) param_ has been properly initialized.

- [ParamList](#) [params_](#)

The parameter list.

7.5.1 Detailed Description

Class providing methods to process a simulation to extract the Density of States starting from a parameter list.

Definition at line 36 of file dosModel.h.

7.5.2 Constructor & Destructor Documentation

7.5.2.1 [DosModel](#) (const [ParamList](#) & *params*) [explicit]

Explicit conversion constructor.

Parameters

in	<i>params</i>	: a parameter list.
----	---------------	---------------------

Definition at line 19 of file dosModel.cc.

7.5.3 Member Function Documentation

7.5.3.1 void [simulate](#) (const GetPot & *config*, const std::string & *input_experim*, const std::string & *output_directory*, const std::string & *output_plot_subdir*, const std::string & *output_filename*) const

Perform the simulation.

Parameters

in	<i>config</i>	: the GetPot configuration object;
in	<i>input_experim</i>	: the file containing experimental data;
in	<i>output_directory</i>	: directory where to store output files;
in	<i>output_plot_subdir</i>	: sub-directory where to store Gnuplot files;

in	<i>output_filename</i>	: prefix for the output filename.
----	------------------------	-----------------------------------

Definition at line 22 of file dosModel.cc.

7.5.3.2 void post_process (const GetPot & *config*, const std::string & *input_experim*, std::ostream & *output_fitting*, std::ostream & *output_CV*, const VectorXr & *x_semic*, const VectorXr & *dens*, const VectorXr & *V_simulated*, const VectorXr & *C_simulated*) const

Perform post-processing.

Parameters

in	<i>config</i>	: the GetPot configuration object;
in	<i>input_experim</i>	: the file containing experimental data;
out	<i>output_fitting</i>	: output file containing infos about fitting experimental data;
out	<i>output_CV</i>	: output file containing infos about capacitance-voltage data;
in	<i>x_semic</i>	: the mesh corresponding to the semiconductor domain;
in	<i>dens</i>	: charge density;
in	<i>V_simulated</i>	: simulated voltage values;
in	<i>C_simulated</i>	: simulated capacitance values.

Definition at line 256 of file dosModel.cc.

7.5.3.3 void gnuplot_commands (const std::string & *output_CV_filename*, std::ostream & *os*) const

Defines commands to generate [Gnuplot](#) output files.

Parameters

in	<i>output_CV_filename</i>	: output CV filename;
out	<i>os</i>	: output stream.

Definition at line 349 of file dosModel.cc.

7.5.3.4 void save_plot (const std::string & *output_directory*, const std::string & *output_plot_subdir*, const std::string & *output_CV_filename*, const std::string & *output_filename*) const

Save the [Gnuplot](#) output files.

Parameters

in	<i>output_directory</i>	: directory where to store output files;
in	<i>output_plot_subdir</i>	: sub-directory where to store Gnuplot files;
in	<i>output_CV_filename</i>	: output CV filename;
in	<i>output_filename</i>	: prefix for the output filename.

Definition at line 378 of file dosModel.cc.

The documentation for this class was generated from the following files:

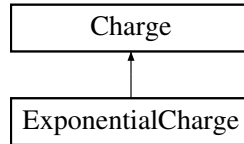
- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[dosModel.h](#)
- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[dosModel.cc](#)

7.6 ExponentialCharge Class Reference

Class derived from [Charge](#), under the hypothesis that Density of States is a single exponential.

```
#include <charge.h>
```

Inheritance diagram for ExponentialCharge:



Public Member Functions

- [ExponentialCharge](#) ()=delete
Default constructor (deleted since it is required to specify a [ParamList](#) and a [QuadratureRule](#)).
- [ExponentialCharge](#) (const [ParamList](#) &, const [QuadratureRule](#) &)
Constructor.
- virtual [~ExponentialCharge](#) ()=default
Destructor (defaulted).
- virtual [VectorXr](#) charge (const [VectorXr](#) &) override
Compute the total charge.
- virtual [VectorXr](#) dcharge (const [VectorXr](#) &) override
Compute the derivative of the total charge with respect to the electric potential.

Private Member Functions

- [Real](#) n_approx (const [Real](#) &, const [Real](#) &, const [Real](#) &) const
Compute electrons density (per unit volume).
- [Real](#) dn_approx (const [Real](#) &, const [Real](#) &, const [Real](#) &) const
Compute the approximate derivative of electrons density (per unit volume) with respect to the electric potential.

Private Attributes

- [Real](#) N0_
Parameter of the exponential density.

Additional Inherited Members

7.6.1 Detailed Description

Class derived from [Charge](#), under the hypothesis that Density of States is a single exponential.

Provide methods to compute total electric charge and its derivative under the hypothesis that Density of States is a single exponential, whose parameter is got by the constructor, of the form:

$$\frac{N_0}{\lambda} \exp\left(-\frac{(\cdot)}{\lambda}\right).$$

Definition at line 122 of file charge.h.

7.6.2 Constructor & Destructor Documentation

7.6.2.1 ExponentialCharge (const ParamList & *params*, const QuadratureRule & *rule*)

Constructor.

Parameters

in	<i>params</i>	: the list of simulation parameters;
in	<i>rule</i>	: a quadrature rule.

Definition at line 107 of file charge.cc.

7.6.3 Member Function Documentation

7.6.3.1 VectorXr charge (const VectorXr & *phi*) [override],[virtual]

Compute the total charge.

Parameters

in	<i>phi</i>	: the electric potential φ .
----	------------	--------------------------------------

Returns

the total charge q [C].

Implements [Charge](#).

Definition at line 138 of file charge.cc.

7.6.3.2 VectorXr dcharge (const VectorXr & *phi*) [override],[virtual]

Compute the derivative of the total charge with respect to the electric potential.

Parameters

in	<i>phi</i>	: the electric potential φ .
----	------------	--------------------------------------

Returns

the derivative: $\frac{dq}{d\varphi}$ [C · V⁻¹].

Implements [Charge](#).

Definition at line 150 of file charge.cc.

7.6.3.3 Real n_approx (const Real & *phi*, const Real & *N0*, const Real & *lambda*) const [private]

Compute electrons density (per unit volume).

Parameters

in	<i>phi</i>	: the electric potential φ ;
in	<i>N0</i>	: the exponential N_0 ;
in	<i>lambda</i>	: the exponential λ .

Returns

the electrons density $n(\varphi)$ [m⁻³].

Definition at line 110 of file charge.cc.

7.6.3.4 Real dn_approx (const Real & *phi*, const Real & *N0*, const Real & *lambda*) const [private]

Compute the approximate derivative of electrons density (per unit volume) with respect to the electric potential.

Parameters

in	<i>phi</i>	: the electric potential φ ;
in	<i>N0</i>	: the exponential N_0 ;
in	<i>lambda</i>	: the exponential λ .

Returns

the derivative: $\frac{dn}{d\varphi} [m^{-3} \cdot V^{-1}]$.

Definition at line 124 of file charge.cc.

The documentation for this class was generated from the following files:

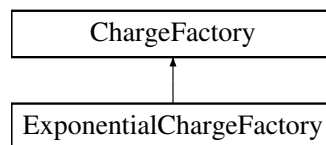
- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/charge.h
- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/charge.cc

7.7 ExponentialChargeFactory Class Reference

Concrete factory to handle a single exponential constitutive relation.

```
#include <factory.h>
```

Inheritance diagram for ExponentialChargeFactory:

**Public Member Functions**

- [ExponentialChargeFactory](#) ()=default
Default constructor (defaulted).
- virtual [~ExponentialChargeFactory](#) ()=default
Destructor (defaulted).
- virtual [Charge](#) * [BuildCharge](#) (const [ParamList](#) &, const [QuadratureRule](#) &) override
Method to build a concrete [Charge](#) object.

7.7.1 Detailed Description

Concrete factory to handle a single exponential constitutive relation.

Definition at line 79 of file factory.h.

7.7.2 Member Function Documentation

7.7.2.1 [Charge](#) * [BuildCharge](#) (const [ParamList](#) & *params*, const [QuadratureRule](#) & *rule*) [override],
[virtual]

Method to build a concrete [Charge](#) object.

Parameters

in	<i>params</i>	: the list of simulation parameters;
in	<i>rule</i>	: a quadrature rule.

Returns

a pointer to [ExponentialCharge](#).

Implements [ChargeFactory](#).

Definition at line 17 of file `factory.cc`.

The documentation for this class was generated from the following files:

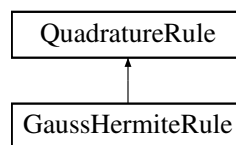
- `/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.h`
- `/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.cc`

7.8 GaussHermiteRule Class Reference

Class derived from [QuadratureRule](#) providing the Gauss-Hermite quadrature rule.

```
#include <quadratureRule.h>
```

Inheritance diagram for GaussHermiteRule:



Public Member Functions

- [GaussHermiteRule](#) ()=delete
Default constructor (deleted since it is required to specify the number of nodes).
- [GaussHermiteRule](#) (const [Index](#) &)
Constructor.
- virtual [~GaussHermiteRule](#) ()=default
Destructor (defaulted).
- virtual void [apply](#) () override
Apply the quadrature rule in order to compute the nodes and weights.
- virtual void [apply](#) (const [GetPot](#) &) override
Apply the quadrature rule reading parameters from a configuration file.
- void [apply_iterative_algorithm](#) (const [Index](#) &=1000, const [Real](#) &=1.0e-14)
Compute nodes and weights using an adapted version of the algorithm presented in: William H. Press, Saul A. Teukolsky, William T. Vetterling, and Brian P. Flannery. 2007. Numerical Recipes: The Art of Scientific Computing (3rd edition). Cambridge University Press, New York, NY, USA.
- void [apply_using_eigendecomposition](#) ()
Compute nodes and weights using an eigendecomposition-based algorithm.

Additional Inherited Members

7.8.1 Detailed Description

Class derived from [QuadratureRule](#) providing the Gauss-Hermite quadrature rule.

Compute nodes and weights for the $nNodes_$ -points approximation of:

$$\int_{-\infty}^{+\infty} w(x)f(x) \, dx$$

where $w(x) = e^{-x^2}$.

Definition at line 89 of file quadratureRule.h.

7.8.2 Constructor & Destructor Documentation

7.8.2.1 GaussHermiteRule (const Index & $nNodes$)

Constructor.

Parameters

<code>in</code>	<code>$nNodes$</code>	: the number of nodes to be used for the quadrature rule.
-----------------	----------------------------------	---

Definition at line 23 of file quadratureRule.cc.

7.8.3 Member Function Documentation

7.8.3.1 void apply (const GetPot & *config*) [override], [virtual]

Apply the quadrature rule reading parameters from a configuration file.

Parameters

<code>in</code>	<code><i>config</i></code>	: the GetPot configuration object.
-----------------	----------------------------	------------------------------------

Implements [QuadratureRule](#).

Definition at line 31 of file quadratureRule.cc.

The documentation for this class was generated from the following files:

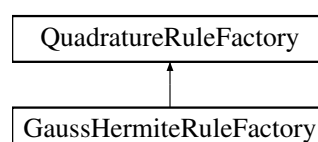
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadratureRule.h](#)
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadratureRule.cc](#)

7.9 GaussHermiteRuleFactory Class Reference

Concrete factory to handle a Gauss-Hermite quadrature rule.

```
#include <factory.h>
```

Inheritance diagram for GaussHermiteRuleFactory:



Public Member Functions

- [GaussHermiteRuleFactory](#) ()=default
Default constructor (defaulted).
- virtual [~GaussHermiteRuleFactory](#) ()=default
Destructor (defaulted).
- virtual [QuadratureRule](#) * [BuildRule](#) (const [Index](#) &) override
Method to build a concrete [QuadratureRule](#) object.

7.9.1 Detailed Description

Concrete factory to handle a Gauss-Hermite quadrature rule.

Definition at line 132 of file `factory.h`.

7.9.2 Member Function Documentation

7.9.2.1 [QuadratureRule](#) * [BuildRule](#) (const [Index](#) & *nNodes*) [override],[virtual]

Method to build a concrete [QuadratureRule](#) object.

Parameters

<i>in</i>	<i>nNodes</i>	: the number of nodes to be used for the quadrature rule.
-----------	---------------	---

Returns

a pointer to [GaussHermiteRule](#).

Implements [QuadratureRuleFactory](#).

Definition at line 22 of file `factory.cc`.

The documentation for this class was generated from the following files:

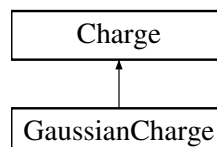
- `/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.h`
- `/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.cc`

7.10 GaussianCharge Class Reference

Class derived from [Charge](#), under the hypothesis that Density of States is a combination of gaussians.

```
#include <charge.h>
```

Inheritance diagram for `GaussianCharge`:



Public Member Functions

- [GaussianCharge](#) ()=delete

Default constructor (deleted since it is required to specify a [ParamList](#) and a [QuadratureRule](#)).

- [GaussianCharge](#) (const [ParamList](#) &, const [QuadratureRule](#) &)

Constructor.

- virtual [~GaussianCharge](#) ()=default

Destructor (defaulted).

- virtual [VectorXr charge](#) (const [VectorXr](#) &) override

Compute the total charge.

- virtual [VectorXr dcharge](#) (const [VectorXr](#) &) override

Compute the derivative of the total charge with respect to the electric potential.

Private Member Functions

- [Real n_approx](#) (const [Real](#) &, const [Real](#) &, const [Real](#) &) const

Compute electrons density (per unit volume).

- [Real dn_approx](#) (const [Real](#) &, const [Real](#) &, const [Real](#) &) const

Compute the approximate derivative of electrons density (per unit volume) with respect to the electric potential.

Additional Inherited Members

7.10.1 Detailed Description

Class derived from [Charge](#), under the hypothesis that Density of States is a combination of gaussians.

Provide methods to compute total electric charge and its derivative under the hypothesis that Density of States is a linear combination of multiple gaussians, whose parameters are read from a [ParamList](#) object, of the form:

$$\frac{N_0}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(\cdot)^2}{2\sigma^2}\right).$$

Definition at line 71 of file charge.h.

7.10.2 Constructor & Destructor Documentation

7.10.2.1 [GaussianCharge](#) (const [ParamList](#) & *params*, const [QuadratureRule](#) & *rule*)

Constructor.

Parameters

in	<i>params</i>	: the list of simulation parameters;
in	<i>rule</i>	: a quadrature rule.

Definition at line 17 of file charge.cc.

7.10.3 Member Function Documentation

7.10.3.1 [VectorXr charge](#) (const [VectorXr](#) & *phi*) [override],[virtual]

Compute the total charge.

Parameters

<i>in</i>	<i>phi</i>	: the electric potential φ .
-----------	------------	--------------------------------------

Returns

the total charge q [C].

Implements [Charge](#).

Definition at line 48 of file charge.cc.

7.10.3.2 VectorXr dcharge (const VectorXr & *phi*) [override], [virtual]

Compute the derivative of the total charge with respect to the electric potential.

Parameters

<i>in</i>	<i>phi</i>	: the electric potential φ .
-----------	------------	--------------------------------------

Returns

the derivative: $\frac{dq}{d\varphi}$ [C · V⁻¹].

Implements [Charge](#).

Definition at line 75 of file charge.cc.

7.10.3.3 Real n_approx (const Real & *phi*, const Real & *N0*, const Real & *sigma*) const [private]

Compute electrons density (per unit volume).

Parameters

<i>in</i>	<i>phi</i>	: the electric potential φ ;
<i>in</i>	<i>N0</i>	: the gaussian mean N_0 ;
<i>in</i>	<i>sigma</i>	: the gaussian standard deviation σ .

Returns

the electrons density $n(\varphi)$ [m⁻³].

Definition at line 20 of file charge.cc.

7.10.3.4 Real dn_approx (const Real & *phi*, const Real & *N0*, const Real & *sigma*) const [private]

Compute the approximate derivative of electrons density (per unit volume) with respect to the electric potential.

Parameters

<i>in</i>	<i>phi</i>	: the electric potential φ ;
<i>in</i>	<i>N0</i>	: the gaussian mean N_0 ;
<i>in</i>	<i>sigma</i>	: the gaussian standard deviation σ .

Returns

the derivative: $\frac{dn}{d\varphi}$ [m⁻³ · V⁻¹].

Definition at line 34 of file charge.cc.

The documentation for this class was generated from the following files:

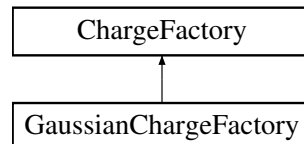
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/charge.h](#)
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/charge.cc](#)

7.11 GaussianChargeFactory Class Reference

Concrete factory to handle a multiple gaussians constitutive relation.

```
#include <factory.h>
```

Inheritance diagram for GaussianChargeFactory:



Public Member Functions

- [GaussianChargeFactory](#) ()=default
Default constructor (defaulted).
- virtual [~GaussianChargeFactory](#) ()=default
Destructor (defaulted).
- virtual [Charge * BuildCharge](#) (const [ParamList](#) &, const [QuadratureRule](#) &) override
Method to build a concrete [Charge](#) object.

7.11.1 Detailed Description

Concrete factory to handle a multiple gaussians constitutive relation.

Definition at line 52 of file factory.h.

7.11.2 Member Function Documentation

7.11.2.1 [Charge * BuildCharge](#) (const [ParamList](#) & *params*, const [QuadratureRule](#) & *rule*) [[override](#)],
[[virtual](#)]

Method to build a concrete [Charge](#) object.

Parameters

in	<i>params</i>	: the list of simulation parameters;
in	<i>rule</i>	: a quadrature rule.

Returns

a pointer to [GaussianCharge](#).

Implements [ChargeFactory](#).

Definition at line 12 of file factory.cc.

The documentation for this class was generated from the following files:

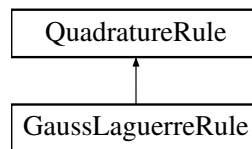
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.h](#)
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.cc](#)

7.12 GaussLaguerreRule Class Reference

Class derived from [QuadratureRule](#) providing the Gauss-Laguerre quadrature rule.

```
#include <quadratureRule.h>
```

Inheritance diagram for GaussLaguerreRule:



Public Member Functions

- [GaussLaguerreRule](#) ()=delete
Default constructor (deleted since it is required to specify the number of nodes).
- [GaussLaguerreRule](#) (const [Index](#) &)
Constructor.
- virtual [~GaussLaguerreRule](#) ()=default
Destructor (defaulted).
- virtual void [apply](#) () override
Apply the quadrature rule in order to compute the nodes and weights.
- virtual void [apply](#) (const [GetPot](#) &) override
Apply the quadrature rule reading parameters from a configuration file.
- void [apply_iterative_algorithm](#) (const [Index](#) &=1000, const [Real](#) &=1.0e-14)
Compute nodes and weights using an adapted version of the algorithm presented in: William H. Press, Saul A. Teukolsky, William T. Vetterling, and Brian P. Flannery. 2007. Numerical Recipes: The Art of Scientific Computing (3rd edition). Cambridge University Press, New York, NY, USA.
- void [apply_using_eigendecomposition](#) ()
Compute nodes and weights using an eigendecomposition-based algorithm.

Static Private Member Functions

- static [Real](#) [log_gamma](#) (const [Real](#) &)
Auxiliary function to compute $\log \Gamma(x)$.

Additional Inherited Members

7.12.1 Detailed Description

Class derived from [QuadratureRule](#) providing the Gauss-Laguerre quadrature rule.

Compute nodes and weights for the $nNodes_$ -points approximation of:

$$\int_0^{+\infty} w(x)f(x) \, dx$$

where $w(x) = e^{-x}$.

Definition at line 132 of file [quadratureRule.h](#).

7.12.2 Constructor & Destructor Documentation

7.12.2.1 GaussLaguerreRule (const Index & *nNodes*)

Constructor.

Parameters

<code>in</code>	<code>nNodes</code>	: the number of nodes to be used for the quadrature rule.
-----------------	---------------------	---

Definition at line 143 of file quadratureRule.cc.

7.12.3 Member Function Documentation

7.12.3.1 `void apply (const GetPot & config) [override], [virtual]`

Apply the quadrature rule reading parameters from a configuration file.

Parameters

<code>in</code>	<code>config</code>	: the GetPot configuration object.
-----------------	---------------------	------------------------------------

Implements [QuadratureRule](#).

Definition at line 151 of file quadratureRule.cc.

7.12.3.2 `Real log_gamma (const Real & x) [static], [private]`

Auxiliary function to compute $\log \Gamma(x)$.

Parameters

<code>in</code>	<code>x</code>	: the point to compute the function at.
-----------------	----------------	---

Returns

the natural logarithm of the gamma function evaluated at x.

Definition at line 258 of file quadratureRule.cc.

The documentation for this class was generated from the following files:

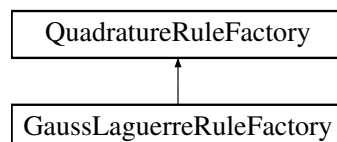
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadratureRule.h](#)
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadratureRule.cc](#)

7.13 GaussLaguerreRuleFactory Class Reference

Concrete factory to handle a Gauss-Laguerre quadrature rule.

```
#include <factory.h>
```

Inheritance diagram for GaussLaguerreRuleFactory:



Public Member Functions

- [GaussLaguerreRuleFactory \(\)](#)=default
Default constructor (defaulted).

- virtual [~GaussLaguerreRuleFactory](#) ()=default
Destructor (defaulted).
- virtual [QuadratureRule](#) * [BuildRule](#) (const [Index](#) &) override
Method to build a concrete [QuadratureRule](#) object.

7.13.1 Detailed Description

Concrete factory to handle a Gauss-Laguerre quadrature rule.

Definition at line 158 of file factory.h.

7.13.2 Member Function Documentation

7.13.2.1 [QuadratureRule](#) * [BuildRule](#) (const [Index](#) & *nNodes*) [override],[virtual]

Method to build a concrete [QuadratureRule](#) object.

Parameters

<i>in</i>	<i>nNodes</i>	: the number of nodes to be used for the quadrature rule.
-----------	---------------	---

Returns

a pointer to [GaussLaguerreRule](#).

Implements [QuadratureRuleFactory](#).

Definition at line 27 of file factory.cc.

The documentation for this class was generated from the following files:

- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[factory.h](#)
- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[factory.cc](#)

7.14 NonLinearPoisson1D Class Reference

Provide a solver for a non-linear Poisson equation.

```
#include <solvers.h>
```

Public Member Functions

- [NonLinearPoisson1D](#) ()=delete
Default constructor (deleted since it is required to specify the solver to be used).
- [NonLinearPoisson1D](#) (const [PdeSolver1D](#) &, const [Index](#) &=100, const [Real](#) &=1.0e-6)
Constructor.
- virtual [~NonLinearPoisson1D](#) ()=default
Destructor (defaulted).
- void [apply](#) (const [VectorXr](#) &, const [VectorXr](#) &, [Charge](#) &)
Apply a Newton method to the equation and then discretize it using the solver specified.

Getter methods

- const [VectorXr](#) & [phi](#) () const
- const [VectorXr](#) & [norm](#) () const
- const [Real](#) & [qTot](#) () const
- const [Real](#) & [cTot](#) () const

Private Member Functions

- [SparseXr computeJac](#) (const [VectorXr](#) &) const
Compute the Jacobi matrix.

Private Attributes

- const [PdeSolver1D](#) & [solver_](#)
Solver handler.
- [Index](#) [maxIterationsNo_](#)
Maximum number of iterations.
- [Real](#) [tolerance_](#)
Tolerance.
- [VectorXr](#) [phi_](#)
The electric potential.
- [VectorXr](#) [norm_](#)
Vector holding L^∞ -norm errors for each iteration.
- [Real](#) [qTot_](#)
Total charge.
- [Real](#) [cTot_](#)
Total capacitance.

7.14.1 Detailed Description

Provide a solver for a non-linear Poisson equation.

A Newton method is applied in order to solve:

$$-\frac{d}{dz} \left(\epsilon(z) \cdot \frac{d\varphi}{dz}(z) \right) = -q \cdot \frac{N_0}{\sqrt{\pi}} \int_{-\infty}^{+\infty} \exp(-\alpha^2) \left(1 + \exp \left(\frac{\sqrt{2}\sigma\alpha - q\varphi(z)}{K_B \cdot T} \right) \right)^{-1} d\alpha .$$

Definition at line 189 of file solvers.h.

7.14.2 Constructor & Destructor Documentation

7.14.2.1 NonLinearPoisson1D (const [PdeSolver1D](#) & *solver*, const [Index](#) & *maxIterationsNo* = 100, const [Real](#) & *tolerance* = 1.0e-6)

Constructor.

Parameters

in	<i>solver</i>	: the solver to be used;
in	<i>maxIterationsNo</i>	: maximum number of iterations desired;
in	<i>tolerance</i>	: tolerance desired.

Definition at line 199 of file solvers.cc.

7.14.3 Member Function Documentation

7.14.3.1 void apply (const [VectorXr](#) & *mesh*, const [VectorXr](#) & *init_guess*, [Charge](#) & *charge_fun*)

Apply a Newton method to the equation and then discretize it using the solver specified.

Parameters

in	<i>mesh</i>	: the mesh;
in	<i>init_guess</i>	: initial guess for the Newton algorithm;
in	<i>charge_fun</i>	: an object of class Charge specifying how to compute total electric charge.

Definition at line 206 of file solvers.cc.

7.14.3.2 SparseXr computeJac (const VectorXr & x) const [private]

Compute the Jacobi matrix.

Parameters

in	<i>x</i>	: the vector where to start from.
----	----------	-----------------------------------

Returns

the Jacobi matrix in a sparse format.

Definition at line 327 of file solvers.cc.

The documentation for this class was generated from the following files:

- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[solvers.h](#)
- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[solvers.cc](#)

7.15 ParamList Class Reference

Class providing methods to handle a list of parameters.

```
#include <paramList.h>
```

Public Member Functions

- [ParamList](#) ()=default
Default constructor (defaulted).
- [ParamList](#) (const [RowVectorXr](#) &)
Explicit conversion constructor.
- virtual [~ParamList](#) ()=default
Destructor (defaulted).

Getter methods

- const [Index](#) & **simulationNo** () const
- const [Real](#) & **t_semic** () const
- const [Real](#) & **t_ins** () const
- const [Real](#) & **eps_semic** () const
- const [Real](#) & **eps_ins** () const
- const [Real](#) & **Wf** () const
- const [Real](#) & **Ea** () const
- const [Real](#) & **NO** () const
- const [Real](#) & **sigma** () const
- const [Real](#) & **NO_2** () const
- const [Real](#) & **sigma_2** () const
- const [Real](#) & **shift_2** () const
- const [Real](#) & **NO_3** () const
- const [Real](#) & **sigma_3** () const

- const [Real](#) & **shift_3** () const
- const [Real](#) & **N0_4** () const
- const [Real](#) & **sigma_4** () const
- const [Real](#) & **shift_4** () const
- const [Real](#) & **N0_exp** () const
- const [Real](#) & **lambda_exp** () const
- const [Index](#) & **nNodes** () const
- const [Index](#) & **nSteps** () const
- const [Real](#) & **V_min** () const
- const [Real](#) & **V_max** () const

Private Attributes

- [Index](#) **simulationNo_**
Simulation number index.
- [Real](#) **t_semic_**
Semiconductor layer thickness [m].
- [Real](#) **t_ins_**
Insulator layer thickness [m].
- [Real](#) **eps_semic_**
Semiconductor layer relative electrical permittivity [].
- [Real](#) **eps_ins_**
Insulator layer relative electrical permittivity [].
- [Real](#) **Wf_**
Work-function [V].
- [Real](#) **Ea_**
Electron affinity [V].
- [Real](#) **N0_**
1st gaussian N_0 [m^{-3}].
- [Real](#) **sigma_**
1st gaussian standard deviation (normalized by $K_B \cdot T$) [].
- [Real](#) **N0_2_**
2nd gaussian N_0 .
- [Real](#) **sigma_2_**
2nd gaussian standard deviation.
- [Real](#) **shift_2_**
2nd gaussian shift with respect to the 1st gaussian electric potential.
- [Real](#) **N0_3_**
3rd gaussian N_0 .
- [Real](#) **sigma_3_**
3rd gaussian standard deviation.
- [Real](#) **shift_3_**
3rd gaussian shift with respect to the 1st gaussian electric potential.
- [Real](#) **N0_4_**
4th gaussian N_0 .
- [Real](#) **sigma_4_**
4th gaussian standard deviation.
- [Real](#) **shift_4_**
4th gaussian shift with respect to the 1st gaussian electric potential.
- [Real](#) **N0_exp_**
Exponential N_0 .
- [Real](#) **lambda_exp_**

- *Exponential λ .*
- [Index nNodes_](#)
Number of nodes that form the mesh.
- [Index nSteps_](#)
Number of steps to simulate.
- [Real V_min_](#)
Minimum voltage [V].
- [Real V_max_](#)
Maximum voltage [V].

Friends

- class **GaussianCharge**
- class **ExponentialCharge**
- class **DosModel**

7.15.1 Detailed Description

Class providing methods to handle a list of parameters.

It can include up to 4 gaussians (later combined to compute total charge) and an exponential.

Definition at line 25 of file paramList.h.

7.15.2 Constructor & Destructor Documentation

7.15.2.1 ParamList (const RowVectorXr & list) [explicit]

Explicit conversion constructor.

Parameters

<i>in</i>	<i>list</i>	: a row vector containing a list of parameters (for example got by a CsvParser object). Parameters should be sorted in the same order as specified above.
-----------	-------------	---

Definition at line 14 of file paramList.cc.

The documentation for this class was generated from the following files:

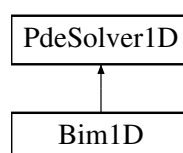
- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[paramList.h](#)
- /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/[paramList.cc](#)

7.16 PdeSolver1D Class Reference

Abstract class providing methods to assemble matrices to solve one-dimensional PDEs.

```
#include <solvers.h>
```

Inheritance diagram for PdeSolver1D:



Public Member Functions

- [PdeSolver1D](#) ()=delete
Default constructor (deleted since it is required to specify the mesh).
- [PdeSolver1D](#) ([VectorXr](#) &)
Constructor.
- virtual [~PdeSolver1D](#) ()=default
Destructor (defaulted).
- virtual void [assembleAdvDiff](#) (const [VectorXr](#) &alpha, const [VectorXr](#) &gamma, const [VectorXr](#) &eta, const [VectorXr](#) &beta)=0
Assemble the matrix for an advection-diffusion term.
- virtual void [assembleStiff](#) (const [VectorXr](#) &eps, const [VectorXr](#) &kappa)=0
Assemble the matrix for a diffusion term.
- virtual void [assembleMass](#) (const [VectorXr](#) &delta, const [VectorXr](#) &zeta)=0
Assemble the matrix for a reaction term.

Getter methods

- const [SparseXr](#) & **AdvDiff** () const
- const [SparseXr](#) & **Stiff** () const
- const [SparseXr](#) & **Mass** () const

Protected Attributes

- [VectorXr](#) [mesh_](#)
The mesh.
- [Index](#) [nNodes_](#)
Number of nodes that form the mesh.
- [SparseXr](#) [AdvDiff_](#)
Matrix for an advection-diffusion term.
- [SparseXr](#) [Stiff_](#)
Stiffness matrix.
- [SparseXr](#) [Mass_](#)
Mass matrix.

Friends

- class **NonLinearPoisson1D**

7.16.1 Detailed Description

Abstract class providing methods to assemble matrices to solve one-dimensional PDEs.

Matrices are held in a sparse format.

Definition at line 31 of file solvers.h.

7.16.2 Constructor & Destructor Documentation

7.16.2.1 [PdeSolver1D](#) ([VectorXr](#) & *mesh*)

Constructor.

Parameters

<code>in</code>	<code>mesh</code>	: the mesh.
-----------------	-------------------	-------------

Definition at line 12 of file solvers.cc.

7.16.3 Member Function Documentation

7.16.3.1 `virtual void assembleAdvDiff (const VectorXr & alpha, const VectorXr & gamma, const VectorXr & eta, const VectorXr & beta)` [pure virtual]

Assemble the matrix for an advection-diffusion term.

Build the matrix for the advection-diffusion problem: $-\nabla \cdot (\alpha \cdot \gamma (\eta \nabla u - \beta u)) = f$.

Parameters

<code>in</code>	<code>alpha</code>	: α , an element-wise constant function;
<code>in</code>	<code>gamma</code>	: γ , an element-wise linear function;
<code>in</code>	<code>eta</code>	: η , an element-wise linear function;
<code>in</code>	<code>beta</code>	: β , an element-wise constant function.

Implemented in [Bim1D](#).

7.16.3.2 `virtual void assembleStiff (const VectorXr & eps, const VectorXr & kappa)` [pure virtual]

Assemble the matrix for a diffusion term.

Build the matrix for the diffusion problem: $-\nabla \cdot (\varepsilon \cdot \kappa \nabla u) = f$.

Parameters

<code>in</code>	<code>eps</code>	: ε , an element-wise constant function;
<code>in</code>	<code>kappa</code>	: κ , an element-wise linear function.

Implemented in [Bim1D](#).

7.16.3.3 `virtual void assembleMass (const VectorXr & delta, const VectorXr & zeta)` [pure virtual]

Assemble the matrix for a reaction term.

Build the mass matrix for the reaction problem: $\delta \cdot \zeta u = f$.

Parameters

<code>in</code>	<code>delta</code>	: δ , an element-wise constant function;
<code>in</code>	<code>zeta</code>	: ζ , an element-wise linear function.

Implemented in [Bim1D](#).

The documentation for this class was generated from the following files:

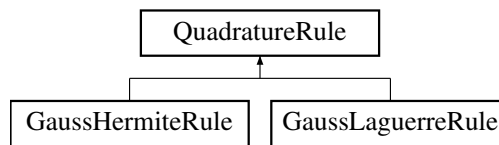
- </home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/solvers.h>
- </home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/solvers.cc>

7.17 QuadratureRule Class Reference

Abstract class providing a quadrature rule.

```
#include <quadratureRule.h>
```


Inheritance diagram for QuadratureRule:



Public Member Functions

- [QuadratureRule](#) ()=delete
Default constructor (deleted since it is required to specify the number of nodes).
- [QuadratureRule](#) (const [Index](#) &)
Constructor.
- virtual [~QuadratureRule](#) ()=default
Destructor (defaulted).
- virtual void [apply](#) ()=0
Apply the quadrature rule in order to compute the nodes and weights.
- virtual void [apply](#) (const [GetPot](#) &config)=0
Apply the quadrature rule reading parameters from a configuration file.

Getter methods

- const [Index](#) & **nNodes** () const
- const [VectorXr](#) & **nodes** () const
- const [VectorXr](#) & **weights** () const

Protected Attributes

- [Index](#) **nNodes_**
Number of nodes of quadrature.
- [VectorXr](#) **nodes_**
Vector containing the computed nodes coordinates.
- [VectorXr](#) **weights_**
Vector containing the computed weights.

Friends

- class **GaussianCharge**
- class **ExponentialCharge**

7.17.1 Detailed Description

Abstract class providing a quadrature rule.

Approximate the integral:

$$\int_a^b f(x) \, dx$$

with the finite sum:

$$\sum_{i=1}^{nNodes_} w_i \cdot f(x_i)$$

where $\{x_i\}_{i=1}^{nNodes_}$ — and $\{w_i\}_{i=1}^{nNodes_}$ — are called respectively nodes and weights.

Definition at line 29 of file quadratureRule.h.

7.17.2 Constructor & Destructor Documentation

7.17.2.1 QuadratureRule (const Index & nNodes)

Constructor.

Parameters

<code>in</code>	<code>nNodes</code>	: the number of nodes to be used for the quadrature rule.
-----------------	---------------------	---

Definition at line 14 of file `quadratureRule.cc`.

7.17.3 Member Function Documentation

7.17.3.1 virtual void apply (const GetPot & config) [pure virtual]

Apply the quadrature rule reading parameters from a configuration file.

Parameters

<code>in</code>	<code>config</code>	: the GetPot configuration object.
-----------------	---------------------	------------------------------------

Implemented in [GaussLaguerreRule](#), and [GaussHermiteRule](#).

The documentation for this class was generated from the following files:

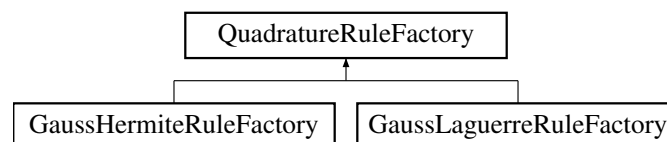
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadratureRule.h](#)
- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadratureRule.cc](#)

7.18 QuadratureRuleFactory Class Reference

Abstract factory to handle at runtime a quadrature rule.

```
#include <factory.h>
```

Inheritance diagram for QuadratureRuleFactory:



Public Member Functions

- [QuadratureRuleFactory](#) ()=default
Default constructor (defaulted).
- virtual [~QuadratureRuleFactory](#) ()=default
Destructor (defaulted).
- virtual [QuadratureRule](#) * [BuildRule](#) (const [Index](#) &nNodes)=0
Method to build an abstract [QuadratureRule](#) object.

7.18.1 Detailed Description

Abstract factory to handle at runtime a quadrature rule.

Definition at line 106 of file `factory.h`.

7.18.2 Member Function Documentation

7.18.2.1 virtual QuadratureRule* BuildRule (const Index & *nNodes*) [pure virtual]

Method to build an abstract [QuadratureRule](#) object.

Parameters

<i>in</i>	<i>nNodes</i>	: the number of nodes to be used for the quadrature rule.
-----------	---------------	---

Returns

a pointer to [QuadratureRule](#).

Implemented in [GaussLaguerreRuleFactory](#), and [GaussHermiteRuleFactory](#).

The documentation for this class was generated from the following file:

- [/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.h](#)

Chapter 8

File Documentation

8.1 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/charge.cc File Reference

```
#include "charge.h"
```

8.1.1 Detailed Description

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [charge.cc](#).

8.2 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/charge.h File Reference

Classes for computing total electric charge.

```
#include "paramList.h"  
#include "quadratureRule.h"  
#include "typedefs.h"
```

Classes

- class [Charge](#)

Abstract class providing methods to calculate total electric charge (the rhs in the Poisson equation).

- class [GaussianCharge](#)

Class derived from [Charge](#), under the hypothesis that Density of States is a combination of gaussians.

- class [ExponentialCharge](#)

Class derived from [Charge](#), under the hypothesis that Density of States is a single exponential.

8.2.1 Detailed Description

Classes for computing total electric charge.

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [charge.h](#).

8.3 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/csvParser.cc File Reference

```
#include "csvParser.h"
```

8.3.1 Detailed Description

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [csvParser.cc](#).

8.4 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/csvParser.h File Reference

Tools to store content from a .csv file in matrices or vectors.

```
#include "typedefs.h"
#include <string>
#include <fstream>
#include <sstream>
#include <utility>
```

Classes

- class [CsvParser](#)

*Class providing methods to read **numeric** content from a .csv file and to store it in [Eigen](#) matrices or vectors.*

8.4.1 Detailed Description

Tools to store content from a .csv file in matrices or vectors.

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [csvParser.h](#).

8.5 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/dosModel.cc File Reference

```
#include "dosModel.h"
```

8.5.1 Detailed Description

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [dosModel.cc](#).

8.6 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/dosModel.h File Reference

Mathematical model for Density of States extraction.

```
#include "charge.h"
#include "csvParser.h"
#include "factory.h"
#include "numerics.h"
#include "paramList.h"
#include "quadratureRule.h"
#include "solvers.h"
#include "typedefs.h"
#include "gnuplot-iostream.h"
#include <chrono>
#include <limits>
```

Classes

- class [DosModel](#)

Class providing methods to process a simulation to extract the Density of States starting from a parameter list.

8.6.1 Detailed Description

Mathematical model for Density of States extraction.

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [dosModel.h](#).

8.7 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.cc File Reference

```
#include "factory.h"
```

8.7.1 Detailed Description

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [factory.cc](#).

8.8 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factory.h File Reference

Abstract factories for the DOS constitutive relation and for the quadrature rule.

```
#include "charge.h"  
#include "paramList.h"  
#include "quadratureRule.h"
```

Classes

- class [ChargeFactory](#)
Abstract factory to handle at runtime a constitutive relation for the Density of States.
- class [GaussianChargeFactory](#)
Concrete factory to handle a multiple gaussians constitutive relation.
- class [ExponentialChargeFactory](#)
Concrete factory to handle a single exponential constitutive relation.
- class [QuadratureRuleFactory](#)
Abstract factory to handle at runtime a quadrature rule.
- class [GaussHermiteRuleFactory](#)
Concrete factory to handle a Gauss-Hermite quadrature rule.
- class [GaussLaguerreRuleFactory](#)
Concrete factory to handle a Gauss-Laguerre quadrature rule.

8.8.1 Detailed Description

Abstract factories for the DOS constitutive relation and for the quadrature rule.

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [factory.h](#).

8.9 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/numerics.cc File Reference

```
#include "numerics.h"
```

8.9.1 Detailed Description

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [numerics.cc](#).

8.10 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/numerics.h File Reference

Generic numeric algorithms.

```
#include "typedefs.h"
#include <limits>
```

Namespaces

- [numerics](#)
Namespace for generic numeric algorithms.

Functions

- `template<typename ScalarType >`
`VectorX< ScalarType > sort (const VectorX< ScalarType > &vector)`
Function to sort [Eigen](#) vectors.
- `template<typename ScalarType >`
`VectorXpair< ScalarType > sort_pair (const VectorX< ScalarType > &vector)`
Function to sort [Eigen](#) vectors, keeping track of indexes.

- **Real trapz** (const [VectorXr](#) &x, const [VectorXr](#) &y)
Function to compute approximate integral of y with spacing increment specified by x, using trapezoidal rule.
- **Real trapz** (const [VectorXr](#) &y)
Compute the approximate integral of y with unit spacing, using trapezoidal rule.
- **VectorXr deriv** (const [VectorXr](#) &, const [VectorXr](#) &)
Compute the numeric derivative: $\frac{dy}{dx}$.
- **Real interp1** (const [VectorXr](#) &, const [VectorXr](#) &, const [Real](#) &)
Linear 1D interpolation. Interpolate y, defined at points x, at the point xNew.
- **VectorXr interp1** (const [VectorXr](#) &, const [VectorXr](#) &, const [VectorXr](#) &)
Linear 1D interpolation. Interpolate y, defined at points x, at the points xNew.
- **Real error_L2** (const [VectorXr](#) &, const [VectorXr](#) &, const [VectorXr](#) &, const [Real](#) &)
Compute the L^2 -norm error between simulated and interpolated values, using trapz.

8.10.1 Detailed Description

Generic numeric algorithms.

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [numerics.h](#).

8.11 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/paramList.cc File Reference

```
#include "paramList.h"
```

8.11.1 Detailed Description

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [paramList.cc](#).

8.12 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/paramList.h File Reference

List of simulation parameters.

```
#include "typedefs.h"
```

Classes

- class [ParamList](#)

Class providing methods to handle a list of parameters.

8.12.1 Detailed Description

List of simulation parameters.

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [paramList.h](#).

8.13 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/physicalConstants.h File Reference

Physical constants.

```
#include "typedefs.h"
```

Namespaces

- [constants](#)

Numerical constants.

Variables

- const [Real Q](#) = 1.602176530000000e-19
Electron charge [C].
- const [Real Q2](#) = Q * Q
Electron charge squared [C²].
- const [Real K_B](#) = 1.380650500000000e-23
Boltzmann's constant [J · K⁻¹].
- const [Real EPS0](#) = 8.854187817e-12
Vacuum electrical permittivity [C · V⁻¹ · m⁻¹].
- const [Real T](#) = 300
Reference temperature [K].
- const [Real V_TH](#) = K_B * T / Q
Threshold voltage [V].

8.13.1 Detailed Description

Physical constants.

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [physicalConstants.h](#).

8.14 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadratureRule.cc File Reference

```
#include "quadratureRule.h"
```

8.14.1 Detailed Description

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [quadratureRule.cc](#).

8.15 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadratureRule.h File Reference

Quadrature rules.

```
#include "typedefs.h"
```

Classes

- class [QuadratureRule](#)
Abstract class providing a quadrature rule.
- class [GaussHermiteRule](#)
Class derived from [QuadratureRule](#) providing the Gauss-Hermite quadrature rule.
- class [GaussLaguerreRule](#)
Class derived from [QuadratureRule](#) providing the Gauss-Laguerre quadrature rule.

8.15.1 Detailed Description

Quadrature rules.

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [quadratureRule.h](#).

8.16 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/solvers.cc File Reference

```
#include "solvers.h"
```

8.16.1 Detailed Description

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [solvers.cc](#).

8.17 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/solvers.h File Reference

Generic solvers for PDEs.

```
#include "charge.h"
#include "typedefs.h"
#include <utility>
#include <limits>
```

Classes

- class [PdeSolver1D](#)
Abstract class providing methods to assemble matrices to solve one-dimensional PDEs.
- class [Bim1D](#)
Class derived from [PdeSolver1D](#), providing a finite volume Box Integration Method (BIM) solver.
- class [NonLinearPoisson1D](#)
Provide a solver for a non-linear Poisson equation.

8.17.1 Detailed Description

Generic solvers for PDEs.

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [solvers.h](#).

8.18 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/typedefs.cc File Reference

```
#include "typedefs.h"
```

8.18.1 Detailed Description

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [typedefs.cc](#).

8.19 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/typedefs.h File Reference

Typedefs and utility functions.

```
#include <Eigen/Dense>
#include <Eigen/Sparse>
#include "GetPot"
#include <iostream>
#include <fstream>
#include "physicalConstants.h"
```

Namespaces

- [constants](#)

Numerical constants.

- [utility](#)

Namespace for utilities and auxiliary functions.

Macros

- `#define Real double`
Pre-processor macro for real numbers.
- `#define Index ptrdiff_t`
Pre-processor macro for indexing variables.

Typedefs

- `typedef Matrix< Real, Dynamic, Dynamic > MatrixXr`
Typedef for dense real-valued dynamic-sized matrices.
- `typedef Matrix< Real, Dynamic, 1 > VectorXr`
Typedef for dense real-valued dynamic-sized column vectors.
- `typedef Matrix< Real, 1, Dynamic > RowVectorXr`
Typedef for dense real-valued dynamic-sized row vectors.
- `typedef SparseMatrix< Real > SparseXr`
Typedef for sparse real-valued dynamic-sized matrices.
- `template<typename ScalarType > using VectorX = Matrix< ScalarType, Dynamic, 1 >`
*Template alias for *Eigen* vectors.*
- `template<typename T > using VectorXpair = VectorX< std::pair< T, Index > >`
*Template alias for an *Eigen* vector of pairs: (ScalarType, Index).*

Functions

- `std::string full_path (const std::string &, const std::string &)`
Auxiliary function to return the full path to a file.
- `void print_block (const char *, std::ostream &=std::cout)`
Auxiliary function to print a string inside a block.
- `void print_done (std::ostream &=std::cout)`
Auxiliary function to print a "DONE!" string.

Variables

- `const Index PARAMS_NO = 24`
Number of parameters required in input file.
- `const Real PI = M_PI`
 π .
- `const Real SQRT_PI = std::sqrt(PI)`
 $\sqrt{\pi}$.
- `const Real PI_M4 = 0.7511255444649425`
 $\pi^{-\frac{1}{4}}$.
- `const Real SQRT_2 = std::sqrt(2)`
 $\sqrt{2}$.

8.19.1 Detailed Description

Typedefs and utility functions.

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [typedefs.h](#).

8.19.2 Typedef Documentation

8.19.2.1 using `VectorX = Matrix<ScalarType, Dynamic, 1>`

Template alias for [Eigen](#) vectors.

Template Parameters

<i>ScalarType</i>	: the scalar type.
-------------------	--------------------

Definition at line 41 of file typedefs.h.

8.19.2.2 using `VectorXpair = VectorX<std::pair<T, Index>>`

Template alias for an [Eigen](#) vector of pairs: (*ScalarType*, *Index*).

Template Parameters

<i>ScalarType</i>	: the scalar type.
-------------------	--------------------

Definition at line 48 of file typedefs.h.

8.20 /home/elauksap/Dropbox/Progetto-PACS/C++/Source/test/simulate_dos.cc File Reference

A test file.

```
#include "src/dosModel.h"
```

Functions

- int [main](#) (const int argc, const char *const *argv, const char *const *envp)
The *main* function.

8.20.1 Detailed Description

A test file.

Author

Pasquale Claudio Africa pasquale.africa@gmail.com

Date

2014

Definition in file [simulate_dos.cc](#).

Index

/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/chargeBim1D, 19
cc, 57 PdeSolver1D, 51
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/chargeBim1D, 19
h, 57 assembleStiff
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/csv- PdeSolver1D, 51
Parser.cc, 58
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/cv-bernoulli
Parser.h, 58 Bim1D, 18
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/dosBim1D, 17
Model.cc, 59 assembleAdvDiff, 18
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/dos- assembleMass, 19
Model.h, 59 assembleStiff, 19
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factoryBernoulli, 18
cc, 60 Bim1D, 18
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/factoryBim1D, 18
h, 60 log_mean, 18
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/numericsBuildCharge
cc, 61 ChargeFactory, 22
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/numericsExponentialChargeFactory, 33
h, 61 GaussianChargeFactory, 41
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/paramBuildRule
List.cc, 62 GaussHermiteRuleFactory, 36
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/paramGaussLaguerreRuleFactory, 43
List.h, 62 QuadratureRuleFactory, 53
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/physicalConstants.h, 63
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadratureCharge, 19
Rule.cc, 64 Charge, 20
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/quadraturecharge, 20
Rule.h, 64 dcharge, 21
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/solverscharge
cc, 65 Charge, 20
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/solversExponentialCharge, 31
h, 65 GaussianCharge, 38
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/typesChargeFactory, 21
cc, 66 BuildCharge, 22
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/src/typescomputeJac
h, 66 NonLinearPoisson1D, 45
/home/elauksap/Dropbox/Progetto-PACS/C++/Source/test/simulateconstants, 11
_dos.cc, 68 CsvParser, 22
apply
GaussHermiteRule, 35
GaussLaguerreRule, 42
NonLinearPoisson1D, 45
QuadratureRule, 53
assembleAdvDiff
Bim1D, 18
PdeSolver1D, 50
assembleMass
Bim1D, 19
PdeSolver1D, 51
assembleStiff
Bim1D, 19
PdeSolver1D, 51
bernoulli
Bim1D, 18
dos
Bim1D, 17
assembleAdvDiff, 18
assembleMass, 19
assembleStiff, 19
bernoulli, 18
Bim1D, 18
log_mean, 18
BuildCharge
ChargeFactory, 22
ExponentialChargeFactory, 33
GaussianChargeFactory, 41
BuildRule
GaussHermiteRuleFactory, 36
GaussLaguerreRuleFactory, 43
QuadratureRuleFactory, 53
Charge, 19
Charge, 20
charge, 20
dcharge, 21
charge
Charge, 20
ExponentialCharge, 31
GaussianCharge, 38
ChargeFactory, 21
BuildCharge, 22
computeJac
NonLinearPoisson1D, 45
constants, 11
CsvParser, 22
CsvParser, 23
CsvParser, 23
importAll, 26
importCell, 26
importCol, 25
importCols, 25
importFirstCols, 25
importFirstRows, 25
importRow, 23
importRows, 23

- dcharge
 - Charge, 21
 - ExponentialCharge, 32
 - GaussianCharge, 38
- deriv
 - numerics, 13
- dn_approx
 - ExponentialCharge, 32
 - GaussianCharge, 40
- DosModel, 26
 - DosModel, 27
 - DosModel, 27
 - gnuplot_commands, 29
 - post_process, 27
 - save_plot, 29
 - simulate, 27
- error_L2
 - numerics, 14
- ExponentialCharge, 29
 - charge, 31
 - dcharge, 32
 - dn_approx, 32
 - ExponentialCharge, 30
 - ExponentialCharge, 30
 - n_approx, 32
- ExponentialChargeFactory, 33
 - BuildCharge, 33
- full_path
 - utility, 15
- GaussHermiteRule, 34
 - apply, 35
 - GaussHermiteRule, 34
 - GaussHermiteRule, 34
- GaussHermiteRuleFactory, 35
 - BuildRule, 36
- GaussLaguerreRule, 41
 - apply, 42
 - GaussLaguerreRule, 42
 - GaussLaguerreRule, 42
 - log_gamma, 42
- GaussLaguerreRuleFactory, 43
 - BuildRule, 43
- GaussianCharge, 37
 - charge, 38
 - dcharge, 38
 - dn_approx, 40
 - GaussianCharge, 38
 - GaussianCharge, 38
 - n_approx, 38
- GaussianChargeFactory, 40
 - BuildCharge, 41
- gnuplot_commands
 - DosModel, 29
- importAll
 - CsvParser, 26
- importCell
 - CsvParser, 26
- importCol
 - CsvParser, 25
- importCols
 - CsvParser, 25
- importFirstCols
 - CsvParser, 25
- importFirstRows
 - CsvParser, 25
- importRow
 - CsvParser, 23
- importRows
 - CsvParser, 23
- interp1
 - numerics, 13, 14
- log_gamma
 - GaussLaguerreRule, 42
- log_mean
 - Bim1D, 18
- n_approx
 - ExponentialCharge, 32
 - GaussianCharge, 38
- NonLinearPoisson1D, 44
 - apply, 45
 - computeJac, 45
 - NonLinearPoisson1D, 45
 - NonLinearPoisson1D, 45
- numerics, 11
 - deriv, 13
 - error_L2, 14
 - interp1, 13, 14
 - sort, 12
 - sort_pair, 12
 - trapz, 13
- ParamList, 46
 - ParamList, 48
 - ParamList, 48
- PdeSolver1D, 48
 - assembleAdvDiff, 50
 - assembleMass, 51
 - assembleStiff, 51
 - PdeSolver1D, 49
 - PdeSolver1D, 49
- post_process
 - DosModel, 27
- print_block
 - utility, 15
- print_done
 - utility, 15
- QuadratureRule, 51
 - apply, 53
 - QuadratureRule, 52
 - QuadratureRule, 52
- QuadratureRuleFactory, 53

- BuildRule, [53](#)
- save_plot
 - DosModel, [29](#)
- simulate
 - DosModel, [27](#)
- sort
 - numerics, [12](#)
- sort_pair
 - numerics, [12](#)
- trapz
 - numerics, [13](#)
- typedefs.h
 - VectorX, [68](#)
 - VectorXpair, [68](#)
- utility, [14](#)
 - full_path, [15](#)
 - print_block, [15](#)
 - print_done, [15](#)
- VectorX
 - typedefs.h, [68](#)
- VectorXpair
 - typedefs.h, [68](#)