

Bose-Hubbard Model Transition Study

1.0

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Chapter 1

Class Index

1.1 Class List

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

| | | |
|----------------------------|---|-------------------|
| BH | Class representing the Bose-Hubbard Hamiltonian | 5 |
| Neighbours | Class to generate the list of neighbours for a 1D chain, 2D square lattice, or 3D cubic lattice . . | 6 |
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Chapter 2

File Index

2.1 File List

Here is a list of all files with brief descriptions:

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Chapter 3

Class Documentation

3.1 BH Class Reference

Class representing the Bose-Hubbard Hamiltonian.

```
#include <hamiltonian.h>
```

Public Member Functions

- [BH](#) (const std::vector< std::vector< int > > &neighbours, int m_, int n_, double J_, double U_, double mu_)
Constructor for the Bose-Hubbard Hamiltonian.
- Eigen::SparseMatrix< double > [getHamiltonian](#) () const
Return the Hamiltonian sparse matrix.

Public Attributes

- Eigen::VectorXd [interaction_matrix](#)

3.1.1 Detailed Description

Class representing the Bose-Hubbard Hamiltonian.

This class implements the Hamiltonian for the Bose-Hubbard model, which describes interacting bosons on a lattice.

Warning

This class is not thread-safe.

3.1.2 Constructor & Destructor Documentation

3.1.2.1 BH()

```
BH::BH (
    const std::vector< std::vector< int > > & neighbours,
    int m_,
    int n_,
    double J_,
    double U_,
    double mu_ )
```

Constructor for the Bose-Hubbard Hamiltonian.

CONSTRUCTOR ///.

Parameters

| | |
|-------------------|--|
| <i>neighbours</i> | Vector that contains the neighbours of each site of the lattice. |
| <i>m</i> | Number of sites in the lattice. |
| <i>n</i> | Number of bosons in the lattice. |
| <i>J</i> | Hopping parameter of the BH model. |
| <i>U</i> | Interaction parameter of the BH model. |
| <i>mu</i> | Chemical potential of the BH model. |

3.1.3 Member Function Documentation**3.1.3.1 getHamiltonian()**

```
Eigen::SparseMatrix< double > BH::getHamiltonian ( ) const
```

Return the Hamiltonian sparse matrix.

UTILITY FUNCTIONS ///.

Returns

Eigen::SparseMatrix<double> The Hamiltonian sparse matrix.

3.1.4 Member Data Documentation**3.1.4.1 interaction_matrix**

```
Eigen::VectorXd BH::interaction_matrix
```

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

- [include/hamiltonian.h](#)
- [src/hamiltonian.cpp](#)

3.2 Neighbours Class Reference

Class to generate the list of neighbours for a 1D chain, 2D square lattice, or 3D cubic lattice.

```
#include <neighbours.h>
```

Public Member Functions

- [Neighbours](#) (int m)
Constructor for the [Neighbours](#) class.
- [~Neighbours](#) ()
Destructor for the [Neighbours](#) class.
- void [chain_neighbours](#) (bool closed=true)
Generate the list of neighbours for a 1D chain.
- void [square_neighbours](#) (bool closed=true)
Generate the list of neighbours for a 2D square lattice.
- void [cube_neighbours](#) (bool closed=true)
Generate the list of neighbours for a 3D cubic lattice.
- std::vector< std::vector< int > > [getNeighbours](#) () const
Return the list of neighbours.

3.2.1 Detailed Description

Class to generate the list of neighbours for a 1D chain, 2D square lattice, or 3D cubic lattice.

Warning

This class is not thread-safe.

3.2.2 Constructor & Destructor Documentation

3.2.2.1 Neighbours()

```
Neighbours::Neighbours (
    int m )
```

Constructor for the [Neighbours](#) class.

Parameters

| | |
|----------|---------------------------------|
| <i>m</i> | Number of sites in the lattice. |
|----------|---------------------------------|

3.2.2.2 ~Neighbours()

```
Neighbours::~Neighbours ( )
```

Destructor for the [Neighbours](#) class.

3.2.3 Member Function Documentation

3.2.3.1 chain_neighbours()

```
void Neighbours::chain_neighbours (
    bool closed = true )
```

Generate the list of neighbours for a 1D chain.

1D ///

Parameters

| | |
|---------------|--|
| <i>m</i> | Number of sites in the chain. |
| <i>closed</i> | By default, closed = true for periodic boundary conditions, closed = false for open boundary conditions. |

Warning

Ensure that the number of sites is greater than 1.

3.2.3.2 cube_neighbours()

```
void Neighbours::cube_neighbours (
    bool closed = true )
```

Generate the list of neighbours for a 2D square lattice.

3D ///

Parameters

| | |
|---------------|--|
| <i>m</i> | Number of sites in the square. |
| <i>closed</i> | By default, closed = true for periodic boundary conditions, closed = false for open boundary conditions. |

Warning

Ensure that the number of sites is a perfect cube.

3.2.3.3 getNeighbours()

```
std::vector< std::vector< int > > Neighbours::getNeighbours ( ) const
```

Return the list of neighbours.

UTILITY FUNCTIONS ///.

Returns

std::vector<std::vector<int>> The list of neighbours for each site of the lattice.

3.2.3.4 square_neighbours()

```
void Neighbours::square_neighbours (
    bool closed = true )
```

Generate the list of neighbours for a 2D square lattice.

2D ///

Parameters

| | |
|---------------|--|
| <i>m</i> | Number of sites in the square. |
| <i>closed</i> | By default, closed = true for periodic boundary conditions, closed = false for open boundary conditions. |

Warning

Ensure that the number of sites is a perfect square.

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

- include/[neighbours.h](#)
- src/[neighbours.cpp](#)

3.3 Operator Class Reference

Class representing an operator in a quantum system.

```
#include <operator.h>
```

Public Member Functions

- [Operator](#) (Eigen::SparseMatrix< double > &&smatrix)
Constructor for the [Operator](#) class.
- int [size](#) () const
Get the size of the matrix.
- [Operator](#) & [operator+](#) (const [Operator](#) &operand)
Add a matrix to an operand of type SparseMatrix with same size.
- [Operator](#) & [operator*](#) (const [Operator](#) &multiplicand)
Multiply a sparse matrix by a multiplicand of type SparseMatrix with same size.
- Eigen::VectorXd [operator*](#) (const Eigen::VectorXd &vector) const
Multiply a sparse matrix by a vector with concomitant size.
- [Operator](#) & [operator*](#) (double scalar)
Multiply a sparse matrix by a scalar.
- Eigen::VectorXcd [IRLM_eigen](#) (int nb_eigen) const
Calculate the approximate eigenvalues and eigenvectors of the Hamiltonian using the Implicitly Restarted Lanczos Method.
- Eigen::VectorXd [FOLM_eigen](#) (int nb_iter, Eigen::MatrixXd &eigenvectors) const
Calculate the approximate eigenvalues and eigenvectors of the Hamiltonian using the Full Orthogonalization Lanczos Method.
- Eigen::VectorXd [exact_eigen](#) (Eigen::MatrixXd &eigenvectors) const
Calculate the exact eigenvalues and eigenvectors of the Hamiltonian by an exact diagonalization.
- double [order_parameter](#) (const Eigen::VectorXd &eigenvalues, const Eigen::MatrixXd &eigenvectors) const
Calculate the order parameter of the system.
- double [gap_ratio](#) ()
Calculate the energy gap ratio of the system.
- void [add_chemical_potential](#) (double mu, int n)
Add a potential term to the operator.

- void [add_interaction](#) (double U, const Eigen::VectorXd &basis)
Add an interaction term to the operator.
- double [partition_function](#) (const Eigen::VectorXd &eigenvalues, double temperature) const
Calculate the partition function Z for an already diagonalized Hamiltonian.
- void [canonical_density_matrix](#) (const Eigen::VectorXd &eigenvalues, double temperature) const
Calculate the canonical density matrix for an already diagonalized Hamiltonian.
- double [boson_density](#) (double dm_u, int n)
Calculate the boson density of the system.
- double [compressibility](#) (double dm_u, int n)
Calculate the isothermal compressibility of the system.

Static Public Member Functions

- static [Operator Identity](#) (int [size](#))
Create the operator Identity.

3.3.1 Detailed Description

Class representing an operator in a quantum system.

This class provides methods for initializing, manipulating, and diagonalizing operators represented as sparse matrices.

Warning

This class is not thread-safe.

3.3.2 Constructor & Destructor Documentation

3.3.2.1 Operator()

```
Operator::Operator (
    Eigen::SparseMatrix< double > && smatrix )
```

Constructor for the [Operator](#) class.

CONSTRUCTOR ///.

Parameters

| | |
|----------------|---|
| <i>smatrix</i> | The sparse matrix to initialize the operator. |
|----------------|---|

3.3.3 Member Function Documentation

3.3.3.1 add_chemical_potential()

```
void Operator::add_chemical_potential (
```

```
double mu,
int n )
```

Add a potential term to the operator.

SPECIFIC CALCULATIONS ///.

3.3.3.2 add_interaction()

```
void Operator::add_interaction (
    double U,
    const Eigen::VectorXd & basis )
```

Add an interaction term to the operator.

3.3.3.3 boson_density()

```
double Operator::boson_density (
    double dmU,
    int n )
```

Calculate the boson density of the system.

Parameters

| | |
|------------|---------------------------------------|
| <i>dmu</i> | The difference of chemical potential. |
| <i>n</i> | The number of bosons. |

Returns

double The boson density.

Warning

This function modifies the values of the operator from μ to $\mu + dm\mu$.

3.3.3.4 canonical_density_matrix()

```
void Operator::canonical_density_matrix (
    const Eigen::VectorXd & eigenvalues,
    double temperature ) const
```

Calculate the canonical density matrix for an already diagonalized Hamiltonian.

Parameters

| | |
|--------------------|----------------------------|
| <i>eigenvalues</i> | The vector of eigenvalues. |
| <i>temperature</i> | The temperature. |

3.3.3.5 compressibility()

```
double Operator::compressibility (
    double dmu,
    int n )
```

Calculate the isothermal compressibility of the system.

Parameters

| | |
|------------|---------------------------------------|
| <i>dmu</i> | The difference of chemical potential. |
| <i>n</i> | The number of bosons. |

Returns

double The compressibility.

Warning

This function modifies the values of the operator from μ to $\mu + d\mu$.

3.3.3.6 exact_eigen()

```
Eigen::VectorXd Operator::exact_eigen (
    Eigen::MatrixXd & eigenvectors ) const
```

Calculate the exact eigenvalues and eigenvectors of the Hamiltonian by an exact diagonalization.

EXACT DIAGONALIZATION ///.

Parameters

| | |
|---------------------|--|
| <i>eigenvectors</i> | An empty matrix to store the eigenvectors. |
|---------------------|--|

Returns

Eigen::Matrix<double> The vector of eigenvalues.

Warning

This function is computationally expensive and should be used with caution.

3.3.3.7 FOLM_eigen()

```
Eigen::VectorXd Operator::FOLM_eigen (
    int nb_iter,
    Eigen::MatrixXd & eigenvectors ) const
```

Calculate the approximate eigenvalues and eigenvectors of the Hamiltonian using the Full Orthogonalization Lanczos Method.

Parameters

| | |
|---------------------|--|
| <i>nb_iter</i> | The number of iterations. |
| <i>eigenvectors</i> | An empty matrix to store the eigenvectors. |

Returns

Eigen::VectorXd The vector of eigenvalues.

Warning

Ensure that `nb_iter` is greater than 1. The calculation might be wrong if the number of iterations is too low.

3.3.3.8 gap_ratio()

```
double Operator::gap_ratio ( )
```

Calculate the energy gap ratio of the system.

Parameters

| | |
|--------------------|----------------------------|
| <i>eigenvalues</i> | The vector of eigenvalues. |
|--------------------|----------------------------|

Returns

double The energy gap ratio.

3.3.3.9 Identity()

```
Operator Operator::Identity (
    int size ) [static]
```

Create the operator Identity.

IDENTITY OPERATOR ///.

Parameters

| | |
|-------------|----------------------------------|
| <i>size</i> | The size of the identity matrix. |
|-------------|----------------------------------|

Returns

[Operator](#) The identity operator.

3.3.3.10 IRLM_eigen()

```
Eigen::VectorXcd Operator::IRLM_eigen (
```

```
int nb_eigen ) const
```

Calculate the approximate eigenvalues and eigenvectors of the Hamiltonian using the Implicitly Restarted Lanczos Method.

IMPLICITLY RESTARTED LANCZOS METHOD (IRLM) ///.

Parameters

| | |
|---------------------|--|
| <i>nb_eigen</i> | The number of eigenvalues to calculate. |
| <i>eigenvectors</i> | An empty matrix to store the eigenvectors. |

Returns

Eigen::Matrix<double> The vector of eigenvalues.

Warning

Ensure that nb_eigen is greater than 1.

3.3.3.11 operator*() [1/3]

```
Eigen::VectorXd Operator::operator* (
    const Eigen::VectorXd & vector ) const
```

Multiply a sparse matrix by a vector with concomitant size.

Parameters

| | |
|---------------|-------------------------|
| <i>vector</i> | The vector to multiply. |
|---------------|-------------------------|

Returns

Eigen::Matrix<T, Eigen::Dynamic, 1> The result of the multiplication.

3.3.3.12 operator*() [2/3]

```
Operator & Operator::operator* (
    const Operator & multiplicand )
```

Multiply a sparse matrix by a multiplicand of type SparseMatrix with same size.

Parameters

| | |
|---------------------|-------------------------|
| <i>multiplicand</i> | The matrix to multiply. |
|---------------------|-------------------------|

Returns

[Operator](#) The result of the multiplication.

Warning

This function modifies the values of the operator.

3.3.3.13 operator*() [3/3]

```
Operator & Operator::operator\* (
    double scalar )
```

Multiply a sparse matrix by a scalar.

Parameters

| | |
|---------------|-------------------------|
| <i>scalar</i> | The scalar to multiply. |
|---------------|-------------------------|

Returns

[Operator](#) The result of the multiplication.

Warning

This function modifies the values of the operator.

3.3.3.14 operator+()

```
Operator & Operator::operator+ (
    const Operator & operand )
```

Add a matrix to an operand of type SparseMatrix with same size.

ADDITION AND MULTIPLICATION ///.

Parameters

| | |
|----------------|--------------------|
| <i>operand</i> | The matrix to add. |
|----------------|--------------------|

Returns

[Operator](#) The result of the addition.

Warning

This function modifies the values of the operator.

3.3.3.15 order_parameter()

```
double Operator::order_parameter (
    const Eigen::VectorXd & eigenvalues,
    const Eigen::MatrixXd & eigenvectors ) const
```

Calculate the order parameter of the system.

Parameters

| | |
|---------------------|-----------------------------|
| <i>eigenvalues</i> | The vector of eigenvalues. |
| <i>eigenvectors</i> | The matrix of eigenvectors. |

Returns

double The order parameter.

3.3.3.16 partition_function()

```
double Operator::partition_function (
    const Eigen::VectorXd & eigenvalues,
    double temperature ) const
```

Calculate the partition function Z for an already diagonalized Hamiltonian.

Parameters

| | |
|--------------------|----------------------------|
| <i>eigenvalues</i> | The vector of eigenvalues. |
| <i>temperature</i> | The temperature. |

Returns

double The partition function.

3.3.3.17 size()

```
int Operator::size ( ) const
```

Get the size of the matrix.

UTILITY FUNCTIONS ///

Returns

int The size of the matrix.

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

- [include/operator.h](#)
- [src/operator.cpp](#)

Chapter 4

File Documentation

4.1 include/hamiltonian.h File Reference

```
#include <vector>
#include <Eigen/Dense>
#include <Eigen/SparseCore>
#include "Eigen/src/Core/Matrix.h"
```

Include dependency graph for hamiltonian.h: This graph shows which files directly or indirectly include this file:

Classes

- class [BH](#)

Class representing the Bose-Hubbard Hamiltonian.

4.2 hamiltonian.h

[Go to the documentation of this file.](#)

```
00001 #pragma once
00002
00003 #include<vector>
00004 #include<Eigen/Dense>
00005 #include<Eigen/SparseCore>
00006 #include "Eigen/src/Core/Matrix.h"
00007
00008
00017 class BH {
00018 private:
00019
00020 // PARAMETERS OF THE BH MODEL
00021
00022     std::vector<std::vector<int>> neighbours; // Vector that contains the neighbours of each site of
the chain
00023
00024     int m; // Number of sites in the chain
00025     int n; // Number of bosons in the chain
00026     int D; // Dimension of the Hilbert space of the system
00027
00028     double J; // Hopping parameter of the BH model
00029     double U; // Interaction parameter of the BH model
00030     double mu; // Chemical potential of the BH model
00031
00032     Eigen::SparseMatrix<double> H; // Sparse matrix representation of the Hamiltonian
00033
00034 // DIMENSION OF THE HILBERT SPACE
00035
00036     /* calculate the dimension of the Hilbert space for n bosons on m sites */
```

```

00037     int binomial(int n, int k) const; // Binomial coefficient
00038     int dimension(int m, int n) const; // Dimension of the Hilbert space
00039
00040 // ELEMENTARY FUNCTIONS
00041
00042     /* calculate the sum of the elements of a vector between 2 index */
00043     int sum(const Eigen::VectorXd& state, int index1, int index2) const;
00044
00045 // INITIALIZE THE HILBERT SPACE BASIS
00046
00047     /* calculate the next state of the Hilbert space in lexicographic order */
00048     bool next_lexicographic(Eigen::VectorXd& state, int m, int n) const;
00049
00050     /* creates a matrix that has the vectors of the Hilbert space basis in columns */
00051     Eigen::MatrixXd init_lexicographic(int m, int n) const;
00052
00053 // SORT THE HILBERT SPACE BASIS TO FACILITATE CALCULUS
00054
00055     /* calculate the unique tag of the kth column of the matrix */
00056     double calculate_tag(const Eigen::MatrixXd& basis, const std::vector<int>& primes, int k) const;
00057
00058     /* calculate and store the tags of each state of the Hilbert space basis */
00059     Eigen::VectorXd calculate_tags(const Eigen::MatrixXd& basis, const std::vector<int>& primes)
00060     const;
00061
00062     /* sort the states of the Hilbert space by ascending order compared by their tags */
00063     void sort_basis(Eigen::VectorXd& tags, Eigen::MatrixXd& basis) const;
00064
00065     /* gives the index of the wanted tag x by the Newton method */
00066     int search_tag(const Eigen::VectorXd& tags, double x) const;
00067
00068 // FILL THE HAMILTONIAN OF THE SYSTEM
00069
00070     /* fill the hopping term of the Hamiltonian */
00071     void fill_hopping(const Eigen::MatrixXd& basis, const Eigen::VectorXd& tags, const
00072     std::vector<std::vector<int>& neighbours, const std::vector<int>& primes, Eigen::SparseMatrix<double>&
00073     hmatrix, double J) const;
00074
00075     /* fill the interaction term of the Hamiltonian */
00076     void fill_interaction(const Eigen::MatrixXd& basis, Eigen::SparseMatrix<double>& hmatrix, double
00077     U) const;
00078
00079     /* fill the chemical potential term of the Hamiltonian */
00080     void fill_chemical(const Eigen::MatrixXd& basis, Eigen::SparseMatrix<double>& hmatrix, double mu)
00081     const;
00082
00083 public:
00084     Eigen::VectorXd interaction_matrix; // Vector that contains the interaction matrix elements
00085
00086 // CONSTRUCTOR
00087
00088     BH(const std::vector<std::vector<int>& neighbours, int m_, int n_, double J_, double U_, double
00089     mu_);
00090
00091 // UTILITY FUNCTIONS
00092
00093     Eigen::SparseMatrix<double> getHamiltonian() const;
00094 };

```

4.3 include/neighbours.h File Reference

```

#include <vector>
#include <cmath>

```

Include dependency graph for neighbours.h: This graph shows which files directly or indirectly include this file:

Classes

- class [Neighbours](#)

Class to generate the list of neighbours for a 1D chain, 2D square lattice, or 3D cubic lattice.

4.4 neighbours.h

[Go to the documentation of this file.](#)

```
00001 #pragma once
00002
00003 #include <vector>
00004 #include <cmath>
00005
00006
00013 class Neighbours {
00014 public:
00015
00021     Neighbours(int m);
00022
00026     ~Neighbours();
00027
00035     void chain_neighbours(bool closed = true);
00036
00044     void square_neighbours(bool closed = true);
00045
00053     void cube_neighbours(bool closed = true);
00054
00059     std::vector<std::vector<int>> getNeighbours() const;
00060
00061 private:
00062     int m;
00063     std::vector<std::vector<int>> neighbours;
00064 };
```

4.5 include/operator.h File Reference

```
#include <cmath>
#include <Eigen/Dense>
#include <Eigen/SparseCore>
#include <Eigen/Eigenvalues>
#include <Spectra/GenEigsSolver.h>
#include <Spectra/MatOp/SparseGenMatProd.h>
```

Include dependency graph for operator.h: This graph shows which files directly or indirectly include this file:

Classes

- class [Operator](#)

Class representing an operator in a quantum system.

4.6 operator.h

[Go to the documentation of this file.](#)

```
00001 #pragma once
00002
00003 #include <cmath>
00004 #include <Eigen/Dense>
00005 #include <Eigen/SparseCore>
00006 #include <Eigen/Eigenvalues>
00007 #include <Spectra/GenEigsSolver.h>
00008 #include <Spectra/MatOp/SparseGenMatProd.h>
00009
00010
00018 class Operator {
00019 private:
00020
00021 // INITIALIZATION :
00022
00023     Eigen::SparseMatrix<double> O;
00024     int D; // dimension of the Hilbert space of the system
00025     double ref; // threshold under which a value is considered null
```

```

00026
00027 // DIAGONALIZATION :
00028
00029 /* implement the Full Orthogonalization Lanczos Method for a sparse matrix for nb_iter iterations
starting with vector v_0 */
00030 void FOLM_diag(int nb_iter, Eigen::VectorXd& v_0, Eigen::MatrixXd& T, Eigen::MatrixXd& V) const;
00031
00032 /* sort eigenvalues and eigenvectors in descending order */
00033 void sort_eigen(Eigen::VectorXd& eigenvalues, Eigen::MatrixXd& eigenvectors) const;
00034
00035 public:
00036
00037 // CONSTRUCTOR :
00038
00039 Operator(Eigen::SparseMatrix<double>&& smatrix);
00040
00041 //UTILITY FUNCTIONS :
00042
00043 int size() const;
00044
00045 // BASIS OPERATIONS :
00046
00047 static Operator Identity(int size);
00048
00049 Operator& operator + (const Operator& operand);
00050
00051 Operator& operator * (const Operator& multiplicand);
00052
00053 Eigen::VectorXd operator * (const Eigen::VectorXd& vector) const;
00054
00055 Operator& operator * (double scalar);
00056
00057 // DIAGONALIZATION :
00058
00059 Eigen::VectorXd IRLM_eigen(int nb_eigen) const;
00060
00061 Eigen::VectorXd FOLM_eigen(int nb_iter, Eigen::MatrixXd& eigenvectors) const;
00062
00063 Eigen::VectorXd exact_eigen(Eigen::MatrixXd& eigenvectors) const;
00064
00065 // PHASE TRANSITION CALCULATIONS :
00066
00067 double order_parameter(const Eigen::VectorXd& eigenvalues, const Eigen::MatrixXd& eigenvectors)
const;
00068
00069 double gap_ratio();
00070
00071 void add_chemical_potential(double mu, int n);
00072
00073 void add_interaction(double U, const Eigen::VectorXd& basis);
00074
00075 // THERMODYNAMICAL FUNCTIONS :
00076
00077 double partition_function(const Eigen::VectorXd& eigenvalues, double temperature) const;
00078
00079 void canonical_density_matrix(const Eigen::VectorXd& eigenvalues, double temperature) const;
00080
00081 double boson_density(double dmu, int n);
00082
00083 double compressibility(double dmu, int n);
00084
00085 };

```

4.7 src/hamiltonian.cpp File Reference

```

#include <vector>
#include <Eigen/Dense>
#include <Eigen/SparseCore>
#include "hamiltonian.h"

```

Include dependency graph for hamiltonian.cpp:

4.8 src/main.cpp File Reference

```

#include <Eigen/Dense>
#include <Eigen/SparseCore>

```



```
#include <Eigen/Eigenvalues>
#include <cmath>
#include <fstream>
#include <iostream>
#include <vector>
#include <chrono>
#include <complex>
#include <getopt.h>
#include "hamiltonian.h"
#include "operator.h"
#include "neighbours.h"
Include dependency graph for main.cpp:
```

Functions

- void [print_usage](#) ()
- int [main](#) (int argc, char *argv[])

4.8.1 Function Documentation

4.8.1.1 main()

```
int main (
    int argc,
    char * argv[] )
```

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4.8.1.2 print_usage()

```
void print_usage ( )
```

4.9 src/neighbours.cpp File Reference

```
#include <vector>
#include <stdexcept>
#include <cmath>
#include "neighbours.h"
Include dependency graph for neighbours.cpp:
```

4.10 src/operator.cpp File Reference

```
#include <stdexcept>
#include <cmath>
#include <complex>
#include <Eigen/Dense>
#include <Eigen/SparseCore>
#include <Eigen/Eigenvalues>
#include <Spectra/GenEigsSolver.h>
#include <Spectra/MatOp/SparseGenMatProd.h>
#include "operator.h"
Include dependency graph for operator.cpp:
```


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