HElib

Implementing Homomorphic Encryption

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Chapter 1

HElib v1.0.2 Documentation

HElib is an open-source (Apache License v2.0) software library that implements homomorphic encryption (HE). Currently available schemes are the implementations of the Brakerski-Gentry-Vaikuntanathan (BGV) scheme and the Approximate Number scheme of Cheon-Kim-Kim-Song (CKKS), along with many optimizations to make homomorphic evaluation runs faster, focusing mostly on effective use of the Smart-Vercauteren ciphertext packing techniques and the Gentry-Halevi-Smart optimizations.

Articles that describe some aspects of HElib include:

- A (somewhat outdated) design document, Shai Halevi and Victor Shoup, April 2013.
- Algorithms in HElib, Shai Halevi and Victor Shoup, published in CRYPTO 2014.
- Bootstrapping for HElib, Shai Halevi and Victor Shoup, EUROCRYPT 2015.

Since mid-2018 HElib has been under extensive refactoring for *Reliability*, Robustness & Serviceability∗, *Performance*, and most importantly *Usability* for researchers and developers working on HE and its uses.

HElib supports an **"assembly language for HE"**, providing low-level routines (set, add, multiply, shift, etc.), sophisticated automatic noise management, improved BGV bootstrapping, multi-threading, and also support for Ptxt (plaintext) objects which mimics the functionality of Ctxt (ciphertext) objects. See changes.md for more details.

HElib is written in C++14 and uses the NTL mathematical library, over GMP.

HElib is distributed under the terms of the Apache License v2.0.

For code downloads and full installation instructions, visit HElib GitHub Pages.

Chapter 2

Namespace Index

2.1 Namespace List

Here is a list of all namespaces with brief descriptions:

Chapter 3

Hierarchical Index

3.1 Class Hierarchy

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

Chapter 4

Class Index

4.1 Class List

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

Chapter 5

File Index

5.1 File List

Here is a list of all files with brief descriptions:

Chapter 6

Namespace Documentation

6.1 Fft Namespace Reference

Functions

- void transform (std::vector< lcx > &vec)
- void inverseTransform (std::vector< lcx > &vec)
- void transformRadix2 (std::vector< lcx > &vec)
- void transformBluestein (std::vector< lcx > &vec)
- void convolve (const std::vector< lcx > &vecx, const std::vector< lcx > &vecy, std::vector< lcx > &vecout)

6.1.1 Function Documentation

6.1.1.1 convolve()

```
void Fft::convolve (
            const std::vector< lcx > & vecx,
            const std::vector< lcx > & vecy,
            std::vector< lcx > & vecout )
```

6.1.1.2 inverseTransform()

```
void Fft::inverseTransform (
            std::vector< lcx > & vec )
```

6.1.1.3 transform()

```
void Fft::transform (
            std::vector< lcx > & vec )
```

6.1.1.4 transformBluestein()

```
void Fft::transformBluestein (
            std::vector< lcx > & vec )
```

6.1.1.5 transformRadix2()

```
void Fft::transformRadix2 (
            std::vector< lcx > & vec )
```

6.2 helib Namespace Reference

Namespaces

- FHEglobals

Classes

- class add_pa_impl
- class AddDAG

  A class representing the logic of the order of bit products when adding two integers.
- class applyPerm_pa_impl
- class ArgMap

  Basic class for arg parsing. Example use:
- class BasicAutomorphPrecon

  Pre-computation to speed many automorphism on the same ciphertext.
- struct BGV

  Type for BGV scheme, to be used as template parameter.
- class BipartitleGraph

  A bipartite flow graph.
- class BlockMatMul1D
- class BlockMatMul1D_derived
- struct BlockMatMul1D_derived_impl
- class BlockMatMul1D_partial
- class BlockMatMul1DExec
- struct BlockMatMul1DExec_construct
- class BlockMatMulFull
- class BlockMatMulFull_derived
- class BlockMatMulFullExec

- struct BlockMatMulFullExec_construct
- class BlockMatMulFullHelper
- struct CKKS

  Type for CKKS scheme, to be used as template parameter.
- class Cmodulus

  Provides FFT and iFFT routines modulo a single-precision prime.
- class ColPerm

  Permuting a single dimension (column) of a hypercube.
- class ConstCubeSlice

  A constant lower-dimension slice of a hypercube.
- struct ConstMultiplier
- struct ConstMultiplier_DoubleCRT
- struct ConstMultiplier_zzX
- struct ConstMultiplierCache
- class Context

  Maintaining the parameters.
- class Ctxt

  A Ctxt object holds a single ciphertext.
- class CtxtPart

  One entry in a ciphertext std::vector.
- class CubeSignature

  Holds a vector of dimensions for a hypercube and some additional data.
- class CubeSlice

  A lower-dimension slice of a hypercube.
- class DAGnode

  A node in an addition-DAG structure.
- class decode_pa_impl
- class deep_clone

  Deep copy: initialize with clone.
- class DoubleCRT

  Implementing polynomials (elements in the ring R_Q) in double-CRT form.
- class DoubleCRTHelper

  A helper class to enforce consistency within an DoubleCRTHelper object.
- class DynamicCtxtPowers

  Store powers of X, compute them dynamically as needed.
- class encode_pa_impl
- class EncryptedArray

  A simple wrapper for a smart pointer to an EncryptedArrayBase. This is the interface that higher-level code should use.
- class EncryptedArrayBase

  virtual class for data-movement operations on arrays of slots
- class EncryptedArrayCx

  A different derived class to be used for the approximate-numbers scheme.
- class EncryptedArrayDerived

  Derived concrete implementation of EncryptedArrayBase.
- class equals_pa_impl
- class EvalMap

  Class that provides the functionality for the linear transforms used in boostrapping. The constructor is invoked with three arguments:
- class Exception

  Base class that other HElib exception classes inherit from.
- class ExplicitReplicator

An implementation of ReplicateHandler that explicitly returns all the replicated ciphertexts in one big vector.

- struct fhe_stats_record
- class FHEtimer

  A simple class to accumulate time.
- class FlowEdge

  An edge in a flow graph.
- class frobeniusAutomorph_pa_impl
- class FullBinaryTree

  A simple implementation of full binary trees (each non-leaf has 2 children)
- class GenDescriptor

  A minimal description of a generator for the purpose of building tree.
- class general_range
- class GeneralAutomorphPrecon
- class GeneralAutomorphPrecon_BSGS
- class GeneralAutomorphPrecon_FULL
- class GeneralAutomorphPrecon_UNKNOWN
- class GeneralBenesNetwork

  Implementation of generalized Benes Permutation Network.
- class GeneratorTrees

  A std::vector of generator trees, one per generator in Zm∗/(p)
- struct half_FFT
- class HyperCube

  A multi-dimensional cube.
- class IndexMap

  IndexMap<T> implements a generic map indexed by a dynamic index set.
- class IndexMapInit

  Initializing elements in an IndexMap.
- class IndexSet

  A dynamic set of non-negative integers.
- class InvalidArgument

  Inherits from Exception and std::invalid_argument.
- class KeySwitch

  Key-switching matrices.
- class LabeledEdge

  A generic directed edge in a graph with some labels.
- class LabeledVertex

  A generic node in a graph with some labels.
- class LogicError

  Inherits from Exception and std::logic_error.
- class MappingData

  Auxiliary structure to support encoding/decoding slots.
- class MatMul1D
- class MatMul1D_derived
- struct MatMul1D_derived_impl
- class MatMul1D_partial
- class MatMul1DExec
- struct MatMul1DExec_construct
- class MatMulExecBase
- class MatMulFull
- class MatMulFull_derived
- class MatMulFullExec
- struct MatMulFullExec_construct

- class MatMulFullHelper
- class ModuliSizes

  A helper class to map required modulo-sizes to primeSets.
- struct mul_BlockMatMul1D_impl
- struct mul_BlockMatMulFull_impl
- struct mul_MatMul1D_impl
- struct mul_MatMulFull_impl
- class mul_pa_impl
- class negate_pa_impl
- class OutOfRangeError

  Inherits from Exception and std::out_of_range.
- class PAlgebra

  The structure of (Z/mZ)$*$ /(p)
- class PAlgebraMod

  The structure of Z[X]/(Phi_m(X), p)
- class PAlgebraModBase

  Virtual base class for PAlgebraMod.
- class PAlgebraModCx
- class PAlgebraModDerived

  A concrete instantiation of the virtual class.
- class PermNetLayer

  The information needed to apply one layer of a permutation network.
- class PermNetwork

  A full permutation network.
- class PGFFT
- class PlaintextArray
- class PlaintextArrayBase
- class PlaintextArrayDerived
- class PolyMod

  An object that contains an `NTL::ZZX` *polynomial along with a coefficient modulus* `p2r` *and a polynomial modulus* `G`*.*
- struct PolyModRing

  Lightweight type for describing the structure of a single slot of the plaintext space.
- class PowerfulConversion

  Conversion between powerful representation in R_m/(q) and zz_pX.
- class PowerfulDCRT

  Conversion between powerful representation, DoubleCRT, and ZZX.
- class PowerfulTranslationIndexes

  Holds index tables for translation between powerful and zz_pX.
- struct PrimeGenerator
- class print_pa_impl
- struct PtrMatrix

  An abstract class for an array of PtrVectors.
- struct PtrMatrix_PtPtrVector

  An implementation of PtrMatrix using vector< PtrVector<T>$*$ >
- struct PtrMatrix_ptVec

  An implementation of PtrMatrix using Vec< Vec<T>$*$ >
- struct PtrMatrix_ptvector

  An implementation of PtrMatrix using vector< vector<T>$*$ >
- struct PtrMatrix_Vec

  An implementation of PtrMatrix using Vec< Vec<T> >
- struct PtrMatrix_vector

An implementation of PtrMatrix using vector< vector<T> >
- struct PtrVector

  Abstract class for an array of objects.
- struct PtrVector_Singleton

  An implementation of PtrVector from a single T object.
- struct PtrVector_slice

  An implementation of PtrVector as a slice of another PtrVector.
- struct PtrVector_VecPt

  An implementation of PtrVector using Vec<T>*
- struct PtrVector_VecT

  An implementation of PtrVector using Vec<T>
- struct PtrVector_vectorPt

  An implementation of PtrVector using vector<T>*
- struct PtrVector_vectorT

  An implementation of PtrVector using vector<T>
- class Ptxt

  An object that mimics the functionality of the `Ctxt` object, and acts as a convenient entry point for inputting/encoding data which is to be encrypted.
- class PubKey

  The public key.
- struct PubKeyHack
- struct quarter_FFT
- class random_pa_impl
- class RandomBlockMatrix
- class RandomFullBlockMatrix
- class RandomFullMatrix
- class RandomMatrix
- class RandomMultiBlockMatrix
- class RandomMultiMatrix
- class RandomState

  Facility for "restoring" the NTL PRG state.
- class RecryptData

  A structure to hold recryption-related data inside the Context.
- class replicate_pa_impl
- class ReplicateHandler

  An abstract class to handle call-backs to get the output of replicate.
- class rotate_pa_impl
- class RuntimeError

  Inherits from Exception and std::runtime_error.
- class ScratchCell

  A class to help manage the allocation of temporary Ctxt objects.
- class SecKey

  The secret key.
- class shallow_clone

  Shallow copy: initialize with copy constructor.
- class shift_pa_impl
- class SKHandle

  A handle, describing the secret-key element that "matches" a part, of the form s^r(X^t).
- class sub_pa_impl
- class SubDimension

  A node in a tree relative to some generator.
- class ThinEvalMap

Class that provides the functionality for the linear transforms used in "thin" boostrapping, where slots are assumed to contain constants. The interface is exactly the same as for EvalMap, except that the constructor does not have a normal_basis parameter.

- class ThinRecryptData

  Same as above, but for "thin" bootstrapping, where the slots are assumed to contain constants.

- class TreeNode

  A node in a full binary tree.

- class zz_pXModulus1

  Auxiliary classes to facilitate faster reduction mod Phi_m(X) when the input has degree less than m.

- class ZZ_pXModulus1

  placeholder for pXModulus ...no optimizations

Typedefs

- typedef PtrVector< Ctxt > CtPtrs
- typedef PtrVector_VecT< Ctxt > CtPtrs_VecCt
- typedef PtrVector_vectorT< Ctxt > CtPtrs_vectorCt
- typedef PtrVector_VecPt< Ctxt > CtPtrs_VecPt
- typedef PtrVector_vectorPt< Ctxt > CtPtrs_vectorPt
- typedef PtrVector_slice< Ctxt > CtPtrs_slice
- typedef PtrMatrix< Ctxt > CtPtrMat
- typedef PtrMatrix_Vec< Ctxt > CtPtrMat_VecCt
- typedef PtrMatrix_vector< Ctxt > CtPtrMat_vectorCt
- typedef PtrMatrix_ptVec< Ctxt > CtPtrMat_ptVecCt
- typedef PtrMatrix_ptvector< Ctxt > CtPtrMat_ptvectorCt
- typedef std::shared_ptr< DoubleCRT > DCRTptr
- typedef std::shared_ptr< NTL::ZZX > ZZXptr
- typedef std::complex< double > cx_double
- typedef std::unordered_map< long, FlowEdge > FNeighborList
- typedef std::vector< FNeighborList > FlowGraph
- typedef std::unordered_multimap< long, LabeledEdge > LNeighborList
- typedef long LONG
- typedef NTL::Vec< long > Permut

  A simple permutation is just a vector with p[i]=\pi_i.

- typedef FullBinaryTree< SubDimension > OneGeneratorTree
- typedef NTL::Vec< long > zzX
- typedef std::pair< long, long > NodeIdx
- template<class T >
  using aligned_vector = PGFFT::aligned_vector< T >
- typedef complex< double > cmplx_t
- typedef long double ldbl

Enumerations

- enum PA_tag { PA_GF2_tag, PA_zz_p_tag, PA_cx_tag }

Functions

- template<typename ExceptionTy = ::helib::LogicError, typename T = void>
  void assertTrue (const T &value, const std::string &message)
- template<typename ExceptionTy = ::helib::LogicError, typename T = void>
  void assertFalse (T value, const std::string &message)
- template<typename ExceptionTy = ::helib::LogicError, typename T = void>
  void assertEq (const T &a, const T &b, const std::string &message)
- template<typename ExceptionTy = ::helib::LogicError, typename T = void>
  void assertNeq (const T &a, const T &b, const std::string &message)
- template<typename ExceptionTy = ::helib::LogicError, typename T = void>
  void assertNotNull (const T &p, const std::string &message)
- template<typename ExceptionTy = ::helib::OutOfRangeError, typename T = void>
  void assertInRange (const T &elem, const T &min, const T &max, const std::string &message, bool right_inclusive=false)
- std::vector< long > longToBitVector (long num, long bitSize)

  Returns a number as a vector of bits with LSB on the left.
- void binaryCond (CtPtrs &output, const Ctxt &cond, const CtPtrs &trueValue, const CtPtrs &falseValue)

  Implementation of `output = cond * trueValue + (1 - cond) * falseValue`.
- void binaryMask (CtPtrs &binaryNums, const Ctxt &mask)

  Zeroes the slots of `binaryNums` *where the corresponding slot of* `mask` *is 0.*
- void concatBinaryNums (CtPtrs &output, const CtPtrs &a, const CtPtrs &b)

  Concatenates two binary numbers into a single `CtPtrs` *object. E.g. If* `a=10111, b=00101` *then* `output = 1011100101`.
- void splitBinaryNums (CtPtrs &leftSplit, CtPtrs &rightSplit, const CtPtrs &input)

  Splits a single binary number into two binary numbers `leftSplit` *and* `rightSplit`.
- void leftBitwiseShift (CtPtrs &output, const CtPtrs &input, const long shamt)

  Left shift `input` *by* `shamt`.
- void bitwiseRotate (CtPtrs &output, const CtPtrs &input, long rotamt)

  Rotate `input` *by* `rotamt`.
- void bitwiseXOR (CtPtrs &output, const CtPtrs &lhs, const CtPtrs &rhs)

  Compute a bitwise XOR between `lhs` *and* `rhs`.
- void bitwiseOr (CtPtrs &output, const CtPtrs &lhs, const CtPtrs &rhs)

  Compute a bitwise OR between `lhs` *and* `rhs`.
- void bitwiseAnd (CtPtrs &output, const CtPtrs &lhs, const CtPtrs &rhs)

  Compute a bitwise AND between `lhs` *and* `rhs`.
- void bitwiseAnd (CtPtrs &output, const CtPtrs &input, const std::vector< long > mask)

  Compute a bitwise AND between `input` *and a* `std::vector<long>`.
- void bitwiseNot (CtPtrs &output, const CtPtrs &input)

  Compute a bitwise NOT of `input`.
- void addTwoNumbers (CtPtrs &sum, const CtPtrs &lhs, const CtPtrs &rhs, long sizeLimit=0, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Adds two numbers in binary representation where each ciphertext of the input vector contains a bit.
- void negateBinary (CtPtrs &negation, const CtPtrs &input)

  Negates a number in binary 2's complement representation.
- void subtractBinary (CtPtrs &difference, const CtPtrs &lhs, const CtPtrs &rhs, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Subtracts `rhs` *from* `lhs` *where* `lhs, rhs` *are in 2's complement.*
- long fifteenOrLess4Four (const CtPtrs &out, const CtPtrs &in, long sizeLimit=4)

  Add together up to fifteen {0,1} integers, producing a 4-bit counter.
- void addManyNumbers (CtPtrs &sum, CtPtrMat &numbers, long sizeLimit=0, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Sum an arbitrary amount of numbers in binary representation.

- void multTwoNumbers (CtPtrs &product, const CtPtrs &lhs, const CtPtrs &rhs, bool rhsTwosComplement=false, long sizeLimit=0, std::vector< zzX > ∗unpackSlotEncoding=nullptr)

  Multiply two numbers in binary representation where each ciphertext of the input vector contains a bit.
- void decryptBinaryNums (std::vector< long > &pNums, const CtPtrs &eNums, const SecKey &sKey, const EncryptedArray &ea, bool twosComplement=false, bool allSlots=true)

  Decrypt the binary numbers that are encrypted in eNums.
- void packedRecrypt (const CtPtrs &a, const CtPtrs &b, std::vector< zzX > ∗unpackSlotEncoding)

  Function for packed recryption to recrypt multiple numbers.
- void compareTwoNumbers (CtPtrs &max, CtPtrs &min, Ctxt &mu, Ctxt &ni, const CtPtrs &a, const CtPtrs &b, bool twosComplement=false, std::vector< zzX > ∗unpackSlotEncoding=nullptr)

  Compares two integers in binary `a`, `b`. Returns `max(a, b)`, `min(a, b)` and indicator bits `mu`=(a>b) and `ni`=(a<b)
- void compareTwoNumbers (Ctxt &mu, Ctxt &ni, const CtPtrs &a, const CtPtrs &b, bool twosComplement=false, std::vector< zzX > ∗unpackSlotEncoding=nullptr)

  Compares two integers in binary `a`, `b`. Returns only indicator bits `mu`=(a>b) and `ni`=(a<b).
- int readEyeCatcher (std::istream &str, const char ∗expect)
- void writeEyeCatcher (std::ostream &str, const char ∗eye)
- void write_ntl_vec_long (std::ostream &str, const NTL::vec_long &vl, long intSize=BINIO_64BIT)
- void read_ntl_vec_long (std::istream &str, NTL::vec_long &vl)
- long read_raw_int (std::istream &str)
- int read_raw_int32 (std::istream &str)
- void write_raw_int (std::ostream &str, long num)
- void write_raw_int32 (std::ostream &str, int num)
- void write_raw_double (std::ostream &str, const double d)
- double read_raw_double (std::istream &str)
- void write_raw_xdouble (std::ostream &str, const NTL::xdouble xd)
- NTL::xdouble read_raw_xdouble (std::istream &str)
- void write_raw_ZZ (std::ostream &str, const NTL::ZZ &zz)
- void read_raw_ZZ (std::istream &str, NTL::ZZ &zz)
- template< typename T >
  void write_raw_vector (std::ostream &str, const std::vector< T > &v)
- template<> void write_raw_vector< long > (std::ostream &str, const std::vector< long > &v)
- template<> void write_raw_vector< double > (std::ostream &str, const std::vector< double > &v)
- template< typename T >
  void read_raw_vector (std::istream &str, std::vector< T > &v, T &init)
- template< typename T >
  void read_raw_vector (std::istream &str, std::vector< T > &v)
- template<> void read_raw_vector< long > (std::istream &str, std::vector< long > &v)
- template<> void read_raw_vector< double > (std::istream &str, std::vector< double > &v)
- template< typename T >
  void read_raw_vector (std::istream &str, std::vector< T > &v, const Context &context)
- void BluesteinInit (long n, const NTL::zz_p &root, NTL::zz_pX &powers, NTL::Vec< NTL::mulmod_precon_t > &powers_aux, NTL::fftRep &Rb)

  initialize bluestein
- void BluesteinFFT (NTL::zz_pX &x, long n, const NTL::zz_p &root, const NTL::zz_pX &powers, const NTL::Vec< NTL::mulmod_precon_t > &powers_aux, const NTL::fftRep &Rb)

  apply bluestein
- template< typename X , typename Cloner >
  void swap (cloned_ptr< X, Cloner > &x, cloned_ptr< X, Cloner > &y)
- template< typename X , typename Cloner >
  void swap (copied_ptr< X, Cloner > &x, copied_ptr< X, Cloner > &y)
- long FindM (long k, long nBits, long c, long p, long d, long s, long chosen_m, bool verbose=false)

  Returns smallest parameter m satisfying various constraints:
- void writeContextBase (std::ostream &s, const Context &context)

write [m p r gens ords] data

- void readContextBase (std::istream &s, unsigned long &m, unsigned long &p, unsigned long &r, std::vector< long > &gens, std::vector< long > &ords)

  read [m p r gens ords] data, needed to construct context
- std::unique_ptr< Context > buildContextFromAscii (std::istream &str)
- void writeContextBaseBinary (std::ostream &str, const Context &context)

  write [m p r gens ords] data
- void writeContextBinary (std::ostream &str, const Context &context)
- void readContextBaseBinary (std::istream &s, unsigned long &m, unsigned long &p, unsigned long &r, std::vector< long > &gens, std::vector< long > &ords)

  read [m p r gens ords] data, needed to construct context
- std::unique_ptr< Context > buildContextFromBinary (std::istream &str)
- void readContextBinary (std::istream &str, Context &context)
- void buildModChain (Context &context, long nBits, long nDgts=3, bool willBeBootstrappable=false, long skHwt=0, long resolution=3, long bitsInSpecialPrimes=0)
- void endBuildModChain (Context &context)
- void packedRecrypt (const CtPtrs &cPtrs, const std::vector< zzX > &unpackConsts, const EncryptedArray &ea)
- void packedRecrypt (const CtPtrs &array, const std::vector< zzX > &unpackConsts, const EncryptedArray &ea, long belowLvl)
- void packedRecrypt (const CtPtrMat &m, const std::vector< zzX > &unpackConsts, const EncryptedArray &ea, long belowLvl=LONG_MAX)
- long findMinBitCapacity (const CtPtrs &v)
- long findMinBitCapacity (const CtPtrMat &m)
- long findMinBitCapacity (std::initializer_list< const CtPtrs * > list)
- void innerProduct (Ctxt &result, const CtPtrs &v1, const CtPtrs &v2)
- Ctxt innerProduct (const CtPtrs &v1, const CtPtrs &v2)
- std::ostream & operator<< (std::ostream &s, const SKHandle &handle)
- std::istream & operator>> (std::istream &s, CtxtPart &p)
- std::ostream & operator<< (std::ostream &s, const CtxtPart &p)
- void totalProduct (Ctxt &out, const std::vector< Ctxt > &v)
- void incrementalProduct (std::vector< Ctxt > &v)
- void innerProduct (Ctxt &result, const std::vector< Ctxt > &v1, const std::vector< Ctxt > &v2)
- Ctxt innerProduct (const std::vector< Ctxt > &v1, const std::vector< Ctxt > &v2)
- void innerProduct (Ctxt &result, const std::vector< Ctxt > &v1, const std::vector< DoubleCRT > &v2)

  Compute the inner product of a vectors of ciphertexts and a constant vector.
- Ctxt innerProduct (const std::vector< Ctxt > &v1, const std::vector< DoubleCRT > &v2)
- void innerProduct (Ctxt &result, const std::vector< Ctxt > &v1, const std::vector< NTL::ZZX > &v2)
- Ctxt innerProduct (const std::vector< Ctxt > &v1, const std::vector< NTL::ZZX > &v2)
- void CheckCtxt (const Ctxt &c, const char *label)

  print to cerr some info about ciphertext
- void extractDigits (std::vector< Ctxt > &digits, const Ctxt &c, long r=0)

  Extract the mod-p^r ciphertext.
- void extractDigits (std::vector< Ctxt > &digits, const Ctxt &c, long r, bool shortCut)
- void extendExtractDigits (std::vector< Ctxt > &digits, const Ctxt &c, long r, long e)
- void setupDebugGlobals (SecKey *debug_key, const std::shared_ptr< const EncryptedArray > &debug_ea, NTL::ZZX debug_ptxt=NTL::ZZX{})

  Setup function for setting up the global debug variables.
- void cleanupDebugGlobals ()

  Cleanup function for clearing the global debug variables.
- void decryptAndPrint (std::ostream &s, const Ctxt &ctxt, const SecKey &sk, const EncryptedArray &ea, long flags=0)
- NTL::xdouble embeddingLargestCoeff (const Ctxt &ctxt, const SecKey &sk)
- double realToEstimatedNoise (const Ctxt &ctxt, const SecKey &sk)

- void checkNoise (const Ctxt &ctxt, const SecKey &sk, const std::string &msg, double thresh=10.0)
- bool decryptAndCompare (const Ctxt &ctxt, const SecKey &sk, const EncryptedArray &ea, const PlaintextArray &pa)
- void rawDecrypt (NTL::ZZX &plaintxt, const std::vector< NTL::ZZX > &zzParts, const DoubleCRT &sKey, long q=0)
- template< typename VEC >
  std::ostream & printVec (std::ostream &s, const VEC &v, long nCoeffs=40)
- std::ostream & printZZX (std::ostream &s, const NTL::ZZX &poly, long nCoeffs=40)
- void conv (DoubleCRT &d, const NTL::ZZX &p)
- void conv (NTL::ZZX &p, const DoubleCRT &d)
- NTL::ZZX to_ZZX (const DoubleCRT &d)
- template< typename RX , typename RXModulus >
  void plaintextAutomorph (RX &bb, const RX &a, long k, long m, const RXModulus &PhimX)
- template< typename RX , typename type >
  void plaintextAutomorph (RX &b, const RX &a, long i, long j, const EncryptedArrayDerived< type > &ea)
- EncryptedArrayBase ∗ buildEncryptedArray (const Context &context, const PAlgebraMod &alMod, const N↩TL::ZZX &G=NTL::ZZX::zero())

  A "factory" for building EncryptedArrays.
- std::ostream & operator<< (std::ostream &s, const PlaintextArray &pa)
- void rotate (const EncryptedArray &ea, PlaintextArray &pa, long k)
- void shift (const EncryptedArray &ea, PlaintextArray &pa, long k)
- void encode (const EncryptedArray &ea, PlaintextArray &pa, const std::vector< long > &array)
- void encode (const EncryptedArray &ea, PlaintextArray &pa, const std::vector< NTL::ZZX > &array)
- void encode (const EncryptedArray &ea, PlaintextArray &pa, long val)
- void encode (const EncryptedArray &ea, PlaintextArray &pa, const NTL::ZZX &val)
- void random (const EncryptedArray &ea, PlaintextArray &pa)
- void decode (const EncryptedArray &ea, std::vector< long > &array, const PlaintextArray &pa)
- void decode (const EncryptedArray &ea, std::vector< NTL::ZZX > &array, const PlaintextArray &pa)
- bool equals (const EncryptedArray &ea, const PlaintextArray &pa, const PlaintextArray &other)
- bool equals (const EncryptedArray &ea, const PlaintextArray &pa, const std::vector< long > &other)
- bool equals (const EncryptedArray &ea, const PlaintextArray &pa, const std::vector< NTL::ZZX > &other)
- void add (const EncryptedArray &ea, PlaintextArray &pa, const PlaintextArray &other)
- void sub (const EncryptedArray &ea, PlaintextArray &pa, const PlaintextArray &other)
- void mul (const EncryptedArray &ea, PlaintextArray &pa, const PlaintextArray &other)
- void negate (const EncryptedArray &ea, PlaintextArray &pa)
- void frobeniusAutomorph (const EncryptedArray &ea, PlaintextArray &pa, long j)
- void frobeniusAutomorph (const EncryptedArray &ea, PlaintextArray &pa, const NTL::Vec< long > &vec)
- void applyPerm (const EncryptedArray &ea, PlaintextArray &pa, const NTL::Vec< long > &pi)
- void power (const EncryptedArray &ea, PlaintextArray &pa, long e)
- void runningSums (const EncryptedArray &ea, Ctxt &ctxt)

  A ctxt that encrypts $(x_1, ..., x_n)$ *is replaced by an encryption of* $(y_1, ..., y_n)$*, where* $y_i = sum_{j \leq i} x_j$.
- void print_stats (std::ostream &s)
- const std::vector< double > ∗ fetch_saved_values (const char ∗)
- std::ostream & operator<< (std::ostream &s, const CubeSignature &sig)
- template< typename T >
  void getHyperColumn (NTL::Vec< T > &v, const ConstCubeSlice< T > &s, long pos)
- template< typename T >
  void setHyperColumn (const NTL::Vec< T > &v, const CubeSlice< T > &s, long pos)
- template< typename T >
  void setHyperColumn (const NTL::Vec< T > &v, const CubeSlice< T > &s, long pos, const T &val)
- template< typename T >
  void print3D (const HyperCube< T > &c)
- template< typename T >
  bool operator== (const IndexMap< T > &map1, const IndexMap< T > &map2)

  Comparing maps, by comparing all the elements.

- template<typename T >
  bool operator!= (const IndexMap< T > &map1, const IndexMap< T > &map2)
- IndexSet operator| (const IndexSet &s, const IndexSet &t)

  union
- IndexSet operator& (const IndexSet &s, const IndexSet &t)

  intersection
- IndexSet operator^ (const IndexSet &s, const IndexSet &t)

  exclusive-or
- IndexSet operator/ (const IndexSet &s, const IndexSet &t)

  set minus
- std::ostream & operator<< (std::ostream &str, const IndexSet &set)
- std::istream & operator>> (std::istream &str, IndexSet &set)
- long card (const IndexSet &s)

  Functional cardinality.
- bool empty (const IndexSet &s)
- bool operator<= (const IndexSet &s1, const IndexSet &s2)

  Is s1 subset or equal to s2.
- bool operator< (const IndexSet &s1, const IndexSet &s2)

  Is s1 strict subset of s2.
- bool operator>= (const IndexSet &s1, const IndexSet &s2)

  Is s2 subset or equal to s2.
- bool operator> (const IndexSet &s1, const IndexSet &s2)

  Is s2 strict subset of s1.
- bool disjoint (const IndexSet &s1, const IndexSet &s2)

  Functional disjoint.
- void buildUnpackSlotEncoding (std::vector< zzX > &unpackSlotEncoding, const EncryptedArray &ea)
- void unpack (const CtPtrs &unpacked, const Ctxt &packed, const EncryptedArray &ea, const std::vector< zzX > &unpackSlotEncoding)
- long unpack (const CtPtrs &unpacked, const CtPtrs &packed, const EncryptedArray &ea, const std::vector< zzX > &unpackSlotEncoding)
- void repack (Ctxt &packed, const CtPtrs &unpacked, const EncryptedArray &ea)
- long repack (const CtPtrs &packed, const CtPtrs &unpacked, const EncryptedArray &ea)
- void unpackSlots (std::vector< unsigned long > &value, PlaintextArray &pa, const EncryptedArray &ea)
- void unpackSlots (std::vector< unsigned long > &value, NTL::ZZX &pa, const EncryptedArray &ea)
- void packConstant (zzX &result, unsigned long data, long nbits, const EncryptedArray &ea)
- void packConstants (zzX &result, const std::vector< unsigned long > &data, long nbits, const EncryptedArray &ea)
- void writePubKeyBinary (std::ostream &str, const PubKey &pk)
- void readPubKeyBinary (std::istream &str, PubKey &pk)
- void writeSecKeyBinary (std::ostream &str, const SecKey &sk)
- void readSecKeyBinary (std::istream &str, SecKey &sk)
- double RLWE (DoubleCRT &c0, DoubleCRT &c1, const DoubleCRT &s, long p, NTL::ZZ *prgSeed=nullptr)
- double RLWE1 (DoubleCRT &c0, const DoubleCRT &c1, const DoubleCRT &s, long p)

  Same as RLWE, but assumes that c1 is already chosen by the caller.
- std::ostream & operator<< (std::ostream &str, const KeySwitch &matrix)
- long maximum_flow (FlowGraph &fg, long src, long sink)
- void traceMap (Ctxt &ctxt)
- void mul (PlaintextArray &pa, const MatMul1D &mat)
- void mul (PlaintextArray &pa, const BlockMatMul1D &mat)
- void mul (PlaintextArray &pa, const MatMulFull &mat)
- void mul (PlaintextArray &pa, const BlockMatMulFull &mat)
- long sumOfCoeffs (const zzX &f)
- NTL::ZZ sumOfCoeffs (const NTL::ZZX &f)

- NTL::ZZ sumOfCoeffs (const DoubleCRT &f)
- template<typename T >
  double largestCoeff (const NTL::Vec< T > &f)

  The L-infinity norm of an element (in coefficient representation)
- template<typename T >
  double largestCoeff (const std::vector< T > &f)
- NTL::ZZ largestCoeff (const NTL::ZZX &f)
- NTL::ZZ largestCoeff (const NTL::Vec< NTL::ZZ > &f)
- NTL::ZZ largestCoeff (const DoubleCRT &f)
- double coeffsL2NormSquared (const zzX &f)

  The L2-norm of an element (in coefficient representation)
- NTL::xdouble coeffsL2NormSquared (const NTL::ZZX &f)
- NTL::xdouble coeffsL2NormSquared (const DoubleCRT &f)
- double coeffsL2Norm (const zzX &f)
- NTL::xdouble coeffsL2Norm (const NTL::ZZX &f)
- NTL::xdouble coeffsL2Norm (const DoubleCRT &f)
- double embeddingLargestCoeff (const zzX &f, const PAlgebra &palg)
- double embeddingLargestCoeff (const std::vector< double > &f, const PAlgebra &palg)
- void embeddingLargestCoeff_x2 (double &norm1, double &norm2, const std::vector< double > &f1, const std::vector< double > &f2, const PAlgebra &palg)
- NTL::xdouble embeddingLargestCoeff (const NTL::ZZX &f, const PAlgebra &palg)
- void CKKS_canonicalEmbedding (std::vector< cx_double > &v, const zzX &f, const PAlgebra &palg)
- void CKKS_canonicalEmbedding (std::vector< cx_double > &v, const NTL::ZZX &f, const PAlgebra &palg)
- void CKKS_canonicalEmbedding (std::vector< cx_double > &v, const std::vector< double > &f, const PAlgebra &palg)
- void CKKS_embedInSlots (zzX &f, const std::vector< cx_double > &v, const PAlgebra &palg, double scaling)
- bool setDryRun (bool toWhat=true)
- bool isDryRun ()
- void setAutomorphVals (std::set< long > *aVals)
- bool isSetAutomorphVals ()
- void recordAutomorphVal (long k)
- void setAutomorphVals2 (std::set< long > *aVals)
- bool isSetAutomorphVals2 ()
- void recordAutomorphVal2 (long k)
- long bitSetToLong (long bits, long bitSize)

  Considers `bits` as a vector of bits and returns the value it represents when interpreted as a n-bit 2's complement number, where n is given by `bitSize`.
- long mcMod (long a, long b)

  Routines for computing mathematically correct mod and div.
- long mcDiv (long a, long b)
- long balRem (long a, long q)
- double fsquare (double x)

  Return the square of a number as a double.
- long multOrd (long p, long m)

  Return multiplicative order of p modulo m, or 0 if GCD(p, m) != 1.
- void ppsolve (NTL::vec_zz_pE &x, const NTL::mat_zz_pE &A, const NTL::vec_zz_pE &b, long p, long r)

  Prime power solver.
- void ppsolve (NTL::vec_GF2E &x, const NTL::mat_GF2E &A, const NTL::vec_GF2E &b, long p, long r)

  A version for GF2: must have p == 2 and r == 1.
- void ppInvert (NTL::mat_zz_p &X, const NTL::mat_zz_p &A, long p, long r)

  Compute the inverse mod p^r of an n x n matrix.
- void ppInvert (NTL::mat_zz_pE &X, const NTL::mat_zz_pE &A, long p, long r)
- void ppInvert (NTL::mat_GF2 &X, const NTL::mat_GF2 &A, UNUSED long p, UNUSED long r)
- void ppInvert (NTL::mat_GF2E &X, const NTL::mat_GF2E &A, UNUSED long p, UNUSED long r)

- void buildLinPolyMatrix (NTL::mat_zz_pE &M, long p)
- void buildLinPolyMatrix (NTL::mat_GF2E &M, long p)
- void buildLinPolyCoeffs (NTL::vec_zz_pE &C, const NTL::vec_zz_pE &L, long p, long r)

  Combination of buildLinPolyMatrix and ppsolve.
- void buildLinPolyCoeffs (NTL::vec_GF2E &C, const NTL::vec_GF2E &L, long p, long r)

  A version for GF2: must be called with p == 2 and r == 1.
- void applyLinPoly (NTL::zz_pE &beta, const NTL::vec_zz_pE &C, const NTL::zz_pE &alpha, long p)

  Apply a linearized polynomial with coefficient vector C.
- void applyLinPoly (NTL::GF2E &beta, const NTL::vec_GF2E &C, const NTL::GF2E &alpha, long p)

  A version for GF2: must be called with p == 2 and r == 1.
- double log2 (const NTL::xdouble &x)

  Base-2 logarithm.
- void factorize (std::vector< long > &factors, long N)

  Factoring by trial division, only works for N<2^{60}, only the primes are recorded, not their multiplicity.
- void factorize (std::vector< NTL::ZZ > &factors, const NTL::ZZ &N)
- void factorize (NTL::Vec< NTL::Pair< long, long >> &factors, long N)

  Factoring by trial division, only works for N<2^{60} primes and multiplicities are recorded.
- void pp_factorize (std::vector< long > &factors, long N)

  Prime-power factorization.
- void phiN (long &phiN, std::vector< long > &facts, long N)

  Compute Phi(N) and also factorize N.
- void phiN (NTL::ZZ &phiN, std::vector< NTL::ZZ > &facts, const NTL::ZZ &N)
- long phi_N (long N)

  Compute Phi(N).
- long findGenerators (std::vector< long > &gens, std::vector< long > &ords, long m, long p, const std::vector< long > &candidates=std::vector< long >())
- void FindPrimitiveRoot (NTL::zz_p &r, unsigned long e)

  Find e-th root of unity modulo the current modulus.
- void FindPrimitiveRoot (NTL::ZZ_p &r, unsigned long e)
- long mobius (long n)

  Compute mobius function (naive method as n is small).
- NTL::ZZX Cyclotomic (long N)

  Compute cyclotomic polynomial.
- NTL::ZZX makeIrredPoly (long p, long d)

  Return a degree-d irreducible polynomial mod p.
- long primroot (long N, long phiN)

  Find a primitive root modulo N.
- long ord (long N, long p)

  Compute the highest power of p that divides N.
- bool is2power (long m)
- NTL::ZZX RandPoly (long n, const NTL::ZZ &p)
- void MulMod (NTL::ZZX &out, const NTL::ZZX &f, long a, long q, bool abs)
- void MulMod (NTL::ZZX &out, const NTL::ZZX &f, long a, long q)
- NTL::ZZX MulMod (const NTL::ZZX &f, long a, long q, bool abs)
- NTL::ZZX MulMod (const NTL::ZZX &f, long a, long q)
- void balanced_MulMod (NTL::ZZX &out, const NTL::ZZX &f, long a, long q)
- template<typename T1 , typename T2 >
  void convert (T1 &x1, const T2 &x2)

  A generic template that resolves to NTL's conv routine.
- template<typename T1 , typename T2 >
  void convert (std::vector< T1 > &v1, const std::vector< T2 > &v2)

  generic vector conversion routines

- template<typename T1 , typename T2 >
  void convert (std::vector< T1 > &v1, const NTL::Vec< T2 > &v2)
- template<typename T1 , typename T2 >
  void convert (NTL::Vec< T1 > &v1, const std::vector< T2 > &v2)
- template<typename T >
  void convert (std::vector< T > &v1, const std::vector< T > &v2)

  Trivial type conversion, useful for generic code.
- template<typename T1 , typename T2 >
  T1 convert (const T2 &v2)
- template<typename T >
  std::vector< T > vector_replicate (const T &a, long n)
- template<typename T >
  std::vector< T > Vec_replicate (const T &a, long n)
- long computeProd (const NTL::Vec< long > &vec)

  returns \prod_d vec[d]
- long computeProd (const std::vector< long > &vec)
- void mul (std::vector< NTL::ZZX > &x, const std::vector< NTL::ZZX > &a, long b)
- void div (std::vector< NTL::ZZX > &x, const std::vector< NTL::ZZX > &a, long b)
- void add (std::vector< NTL::ZZX > &x, const std::vector< NTL::ZZX > &a, const std::vector< NTL::ZZX > &b)
- long is_in (long x, int *X, long sz)

  Finds whether x is an element of the set X of size sz, Returns -1 it not and the location if true.
- long CRTcoeff (long p, long q, bool symmetric=false)

  Returns a CRT coefficient: x = (0 mod p, 1 mod q). If symmetric is set then x \in [-pq/2, pq/2), else x \in [0,pq)
- template<class zzvec >
  bool intVecCRT (NTL::vec_ZZ &vp, const NTL::ZZ &p, const zzvec &vq, long q)

  Incremental integer CRT for vectors.
- template<typename T , bool maxFlag>
  long argminmax (std::vector< T > &v)

  Find the index of the (first) largest/smallest element.
- template<typename T >
  long argmax (std::vector< T > &v)
- template<typename T >
  long argmin (std::vector< T > &v)
- long argmax (std::vector< long > &v, bool(*moreThan)(long, long))

  *A variant with a specialized comparison function (*moreThan)(a,b) returns the comparison a>b.*
- bool closeToOne (const NTL::xdouble &x, long p)
- std::pair< long, long > rationalApprox (double x, long denomBound=0)
- std::pair< NTL::ZZ, NTL::ZZ > rationalApprox (NTL::xdouble x, NTL::xdouble denomBound=NTL↩
  ::xdouble(0.0))
- void seekPastChar (std::istream &str, int cc)

  Advance the input stream beyond white spaces and a single instance of the char cc.
- template<typename T >
  void reverse (NTL::Vec< T > &v, long lo, long hi)

  Reverse a vector in place.
- template<typename T >
  void rotate (NTL::Vec< T > &v, long k)

  Rotate a vector in place using swaps.
- template<typename T >
  long lsize (const std::vector< T > &v)

  Size of STL vector as a long (rather than unsigned long)
- template<typename T >
  void killVec (std::vector< T > &vec)

  NTL/std compatibility.

- template< typename T >
  void killVec (NTL::Vec< T > &vec)
- template< typename T >
  void setLengthZero (std::vector< T > &vec)
- template< typename T >
  void setLengthZero (NTL::Vec< T > &vec)
- template< typename T >
  long lsize (const NTL::Vec< T > &v)
- template< typename T >
  void resize (NTL::Vec< T > &v, long sz, const T &val)
- template< typename T >
  void resize (std::vector< T > &v, long sz, const T &val)
- template< typename T >
  void resize (NTL::Vec< T > &v, long sz)
- template< typename T >
  void resize (std::vector< T > &v, long sz)
- template< typename T1 , typename T2 >
  bool sameObject (const T1 *p1, const T2 *p2)

  Testing if two vectors point to the same object.
- void ModComp (NTL::ZZX &res, const NTL::ZZX &g, const NTL::ZZX &h, const NTL::ZZX &f)

  Modular composition of polynomials: res = g(h) mod f.
- long polyEvalMod (const NTL::ZZX &poly, long x, long p)

  Evaluates a modular integer polynomial, returns poly(x) mod p.
- void interpolateMod (NTL::ZZX &poly, const NTL::vec_long &x, const NTL::vec_long &y, long p, long e=1)

  Interpolate polynomial such that poly(x[i] mod p)=y[i] (mod p^e) It is assumed that the points x[i] are all distinct modulo p.
- long divc (long a, long b)

  returns ceiling(a/b); assumes a >=0, b>0, a+b <= MAX_LONG
- void rem (NTL::zz_pX &r, const NTL::zz_pX &a, const zz_pXModulus1 &ff)
- template< typename T >
  std::ostream & operator<< (std::ostream &s, std::vector< T > v)
- template< typename T >
  std::istream & operator>> (std::istream &s, std::vector< T > &v)
- template< typename T >
  std::string vecToStr (const std::vector< T > &v)
- template< typename T >
  NTL::Vec< T > atoVec (const char *a)
- template< typename T >
  std::vector< T > atovector (const char *a)
- void TofftRep_trunc (NTL::fftRep &y, const NTL::zz_pX &x, long k, UNUSED long len, long lo, long hi)
- void TofftRep_trunc (NTL::fftRep &y, const NTL::zz_pX &x, long k, long len)
- template< typename T , typename P , typename... Args>
  void make_lazy (const NTL::Lazy< T, P > &obj, Args &&... args)
- template< typename T , typename P , typename F , typename... Args>
  void make_lazy_with_fun (const NTL::Lazy< T, P > &obj, F f, Args &&... args)
- void Warning (const char *msg)
- void Warning (const std::string &msg)
- PAlgebraModBase * buildPAlgebraMod (const PAlgebra &zMStar, long r)

  Builds a table, of type PA_GF2 if p == 2 and r == 1, and PA_zz_p otherwise.
- bool comparePAlgebra (const PAlgebra &palg, unsigned long m, unsigned long p, unsigned long r, const std::vector< long > &gens, const std::vector< long > &ords)

  returns true if the palg parameters match the rest, false otherwise
- double calcPolyNormBnd (long m)
- template< typename T >
  void applyPermToVec (NTL::Vec< T > &out, const NTL::Vec< T > &in, const Permut &p1)

Apply a permutation to a std::vector, out[i]=in[p1[i]] (NOT in-place)
- template< typename T >
  void applyPermToVec (std::vector< T > &out, const std::vector< T > &in, const Permut &p1)
- template< typename T >
  void applyPermsToVec (NTL::Vec< T > &out, const NTL::Vec< T > &in, const Permut &p2, const Permut &p1)

  Apply two permutations to a std::vector out[i]=in[p2[p1[i]]] (NOT in-place)
- template< typename T >
  void applyPermsToVec (std::vector< T > &out, const std::vector< T > &in, const Permut &p2, const Permut &p1)
- void randomPerm (Permut &perm, long n)

  A random size-n permutation.
- std::ostream & operator<< (std::ostream &s, const ColPerm &p)
- void breakPermByDim (std::vector< ColPerm > &out, const Permut &pi, const CubeSignature &sig)

  Takes a permutation pi over m-dimensional cube C=Z_{n1} x...x Z_{nm} and expresses pi as a product pi = rho_↩ {2m-1} o ... o rho_2 o rho_1 where each rho_i is a column permutation along one dimension. Specifically for i<m, the permutations rho_i and rho_{2(m-1)-i} permute the i'th dimension.
- void polyEval (Ctxt &ret, NTL::ZZX poly, const Ctxt &x, long k=0)

  Evaluate a cleartext polynomial on an encrypted input.
- void polyEval (Ctxt &ret, const NTL::Vec< Ctxt > &poly, const Ctxt &x)

  Evaluate an encrypted polynomial on an encrypted input.
- std::ostream & operator<< (std::ostream &s, const ModuliSizes::Entry &e)
- std::istream & operator>> (std::istream &s, ModuliSizes::Entry &e)
- void write (std::ostream &s, const ModuliSizes::Entry &e)
- void read (std::istream &s, ModuliSizes::Entry &e)
- template< typename T >
  long lsize (const PtrMatrix< T > &v)
- template< typename T >
  void resize (PtrMatrix< T > &v, long newSize)
- template< typename T >
  void setLengthZero (PtrMatrix< T > &v)
- template< typename T >
  const T ∗ ptr2nonNull (std::initializer_list< const PtrVector< T > ∗ > list)
- template< typename T >
  long lsize (const PtrVector< T > &v)
- template< typename T >
  void setLengthZero (PtrVector< T > &v)
- template< typename T >
  void resize (PtrVector< T > &v, long newSize, const T &val)
- template< typename T >
  void resize (PtrVector< T > &v, long newSize, const T ∗val)
- template< typename V1 , typename V2 >
  void vecCopy (V1 &v1, const V2 &v2, long sizeLimit=0)
- template< typename V , typename T >
  void vecCopy (V &v1, const PtrVector< T > &v2, long sizeLimit=0)
- template< typename V , typename T >
  void vecCopy (PtrVector< T > &v1, const V &v2, long sizeLimit=0)
- template< typename T >
  void vecCopy (PtrVector< T > &v1, const PtrVector< T > &v2, long sizeLimit=0)
- template< typename From , typename Scheme >
  std::vector< typename Scheme::SlotType > convertDataToSlotVector (const std::vector< From > &data, const Context &context)

  Converts `std::vector<From>` to `std::vector<Scheme::SlotType>`.
- template< typename Scheme >
  void innerProduct (Ptxt< Scheme > &result, const std::vector< Ptxt< Scheme >> &first_vec, const std↩ ::vector< Ptxt< Scheme >> &second_vec)

Free function that computes the inner product of two vectors of `Ptxt`.

- MatMul1D ∗ buildRandomMatrix (const EncryptedArray &ea, long dim)
- MatMul1D ∗ buildRandomMultiMatrix (const EncryptedArray &ea, long dim)
- BlockMatMul1D ∗ buildRandomBlockMatrix (const EncryptedArray &ea, long dim)
- BlockMatMul1D ∗ buildRandomMultiBlockMatrix (const EncryptedArray &ea, long dim)
- MatMulFull ∗ buildRandomFullMatrix (const EncryptedArray &ea)
- BlockMatMulFull ∗ buildRandomFullBlockMatrix (const EncryptedArray &ea)
- general_range< long > range (long n)
- general_range< long > range (long m, long n)
- void replicate (const EncryptedArray &ea, Ctxt &ctx, long pos)

  The value in slot #pos is replicated in all other slots. On an n-slot ciphertext, this algorithm performs O(log n) 1D rotations.
- void replicate0 (const EncryptedArray &ea, Ctxt &ctxt, long pos)

  A lower-level routine. Same as replicate, but assumes all slots are zero except slot #pos.
- void replicateAll (const EncryptedArray &ea, const Ctxt &ctxt, ReplicateHandler ∗handler, long recBound=64, RepAuxDim ∗repAuxPtr=nullptr)
- void replicateAll (std::vector< Ctxt > &v, const EncryptedArray &ea, const Ctxt &ctxt, long recBound=64, RepAuxDim ∗repAuxPtr=nullptr)
- template<typename Scheme >
  void replicateAll (std::vector< Ptxt< Scheme >> &v, const EncryptedArray &, const Ptxt< Scheme > &ptxt)

  Generate a vector of plaintexts with each slot replicated in each plaintext.
- void replicateAllOrig (const EncryptedArray &ea, const Ctxt &ctxt, ReplicateHandler ∗handler, RepAux ∗rep←AuxPtr=nullptr)
- void replicate (const EncryptedArray &ea, PlaintextArray &pa, long i)
- template<typename Scheme >
  void replicate (const EncryptedArray &, Ptxt< Scheme > &ptxt, long i)

  Replicate single slot of a `Ptxt` object across all of its slots.
- void sampleSmall (zzX &poly, long n, double prob=0.5)
- void sampleSmall (NTL::ZZX &poly, long n, double prob=0.5)
- void sampleHWt (zzX &poly, long n, long Hwt=100)

  Sample a degree-(n-1) poly as above, with only Hwt nonzero coefficients.
- void sampleHWt (NTL::ZZX &poly, long n, long Hwt=100)
- void sampleGaussian (zzX &poly, long n, double stdev)

  Sample polynomials with Gaussian coefficients.
- void sampleGaussian (NTL::ZZX &poly, long n, double stdev)
- void sampleUniform (zzX &poly, long n, long B=100)

  Sample a degree-(n-1) ZZX, with coefficients uniform in [-B,B].
- void sampleUniform (NTL::ZZX &poly, long n, const NTL::ZZ &B=NTL::ZZ(100L))
- void sampleGaussian (std::vector< double > &dvec, long n, double stdev)

  Choose a vector of continuous Gaussians.
- double sampleHWt (zzX &poly, const Context &context, long Hwt=100)
- double sampleHWtBounded (zzX &poly, const Context &context, long Hwt=100)
- double sampleHWtBoundedEffectiveBound (const Context &context, long Hwt=100)
- double sampleSmall (zzX &poly, const Context &context)
- double sampleSmallBounded (zzX &poly, const Context &context)
- double sampleGaussian (zzX &poly, const Context &context, double stdev)
- double sampleGaussianBounded (zzX &poly, const Context &context, double stdev)
- double sampleUniform (zzX &poly, const Context &context, long B=100)
- NTL::xdouble sampleUniform (NTL::ZZX &poly, const Context &context, const NTL::ZZ &B=NTL::ZZ(100L))
- void reduceModPhimX (zzX &poly, const PAlgebra &palg)
- const NTL::zz_pXModulus & getPhimXMod (const PAlgebra &palg)
- void computeAllProducts (CtPtrs &products, const CtPtrs &array, std::vector< zzX > ∗unpackSlot←Encoding=nullptr)

- void tableLookup (Ctxt &out, const std::vector< zzX > &table, const CtPtrs &idx, std::vector< zzX > *unpackSlotEncoding=nullptr)
- void tableWriteIn (const CtPtrs &table, const CtPtrs &idx, std::vector< zzX > *unpackSlotEncoding=nullptr)
- void buildLookupTable (std::vector< zzX > &T, std::function< double(double)> f, long nbits_in, long scale_in, long sign_in, long nbits_out, long scale_out, long sign_out, const EncryptedArray &ea)

    Built a table-lookup for a function in fixed-point representation.
- void registerTimer (FHEtimer *timer)
- unsigned long GetTimerClock ()
- void setTimersOn ()
- void setTimersOff ()
- bool areTimersOn ()
- const FHEtimer * getTimerByName (const char *name)
- void resetAllTimers ()
- void printAllTimers (std::ostream &str=std::cerr)

    Print the value of all timers to stream.
- bool printNamedTimer (std::ostream &str, const char *name)
- bool IsZero (const zzX &a)
- void clear (zzX &a)
- void convert (NTL::zz_pX &x, const zzX &a)
- void add (zzX &res, const zzX &a, const zzX &b)
- zzX operator+ (const zzX &a, const zzX &b)
- zzX & operator+= (zzX &a, const zzX &b)
- void div (zzX &res, const zzX &a, long b)
- zzX operator/ (const zzX &a, long b)
- zzX & operator/= (zzX &a, long b)
- void mul (zzX &res, const zzX &a, long b)
- zzX operator* (const zzX &a, long b)
- zzX & operator*= (zzX &a, long b)
- void normalize (zzX &f)
- void MulMod (zzX &res, const zzX &a, const zzX &b, const PAlgebra &palg)
- zzX MulMod (const zzX &a, const zzX &b, const PAlgebra &palg)
- zzX balanced_zzX (const NTL::zz_pX &f)
- zzX balanced_zzX (const NTL::GF2X &f)
- long defaultPmiddle (long delta)
- long defaultQmiddle (long delta)
- void runningSums (CtPtrs &v)
- void compareTwoNumbersImplementation (CtPtrs &max, CtPtrs &min, Ctxt &mu, Ctxt &ni, const CtPtrs &aa, const CtPtrs &bb, bool twosComplement, std::vector< zzX > *unpackSlotEncoding, bool cmp_only)
- void BluesteinFFT (NTL::zz_pX &x, long n, UNUSED const NTL::zz_p &root, const NTL::zz_pX &powers, const NTL::Vec< NTL::mulmod_precon_t > &powers_aux, const NTL::fftRep &Rb)
- NTL::zz_pContext BuildContext (long p, long maxroot)
- std::ostream & operator<< (std::ostream &str, const Context &context)
- std::istream & operator>> (std::istream &str, Context &context)
- NTL::ZZX getG (const EncryptedArray &ea)
- void addSomePrimes (Ctxt &c)
- void computeIntervalForMul (double &lo, double &hi, const Ctxt &ctxt1, const Ctxt &ctxt2)
- void computeIntervalForSqr (double &lo, double &hi, const Ctxt &ctxt)
- std::istream & operator>> (std::istream &str, SKHandle &handle)
- std::ostream & operator<< (std::ostream &str, const Ctxt &ctxt)
- std::istream & operator>> (std::istream &str, Ctxt &ctxt)
- double log2_realToEstimatedNoise (const Ctxt &ctxt, const SecKey &sk)
- template DoubleCRT & DoubleCRT::Op< DoubleCRT::AddFun > (const DoubleCRT &other, AddFun fun, bool matchIndexSets)
- template DoubleCRT & DoubleCRT::Op< DoubleCRT::SubFun > (const DoubleCRT &other, SubFun fun, bool matchIndexSets)

- template DoubleCRT & DoubleCRT::Op< DoubleCRT::MulFun > (const NTL::ZZ &num, MulFun fun)
- template DoubleCRT & DoubleCRT::Op< DoubleCRT::AddFun > (const NTL::ZZ &num, AddFun fun)
- template DoubleCRT & DoubleCRT::Op< DoubleCRT::SubFun > (const NTL::ZZ &num, SubFun fun)
- template DoubleCRT & DoubleCRT::Op< DoubleCRT::MulFun > (const NTL::ZZX &poly, MulFun fun)
- template DoubleCRT & DoubleCRT::Op< DoubleCRT::AddFun > (const NTL::ZZX &poly, AddFun fun)
- template DoubleCRT & DoubleCRT::Op< DoubleCRT::SubFun > (const NTL::ZZX &poly, SubFun fun)
- std::ostream & operator<< (std::ostream &str, const DoubleCRT &d)
- std::istream & operator>> (std::istream &str, DoubleCRT &d)
- void totalSums (const EncryptedArray &ea, Ctxt &ctxt)
- void applyLinPoly1 (const EncryptedArray &ea, Ctxt &ctxt, const std::vector< NTL::ZZX > &C)
- void applyLinPolyMany (const EncryptedArray &ea, Ctxt &ctxt, const std::vector< std::vector< NTL::ZZX >> &Cvec)
- template<typename P >
  void applyLinPolyLL (Ctxt &ctxt, const std::vector< P > &encodedC, long d)
- template void applyLinPolyLL (Ctxt &ctxt, const std::vector< zzX > &encodedC, long d)
- template void applyLinPolyLL (Ctxt &ctxt, const std::vector< NTL::ZZX > &encodedC, long d)
- template void applyLinPolyLL (Ctxt &ctxt, const std::vector< DoubleCRT > &encodedC, long d)
- void print (const EncryptedArray &ea, std::ostream &s, const PlaintextArray &pa)
- void mapTo01 (const EncryptedArray &ea, Ctxt &ctxt)
- template<typename Scheme >
  void mapTo01 (const EncryptedArray &, Ptxt< Scheme > &ptxt)
- template void mapTo01 (const EncryptedArray &, Ptxt< BGV > &ptxt)
- template void mapTo01 (const EncryptedArray &, Ptxt< CKKS > &ptxt)
- void fastPower (Ctxt &ctxt, long d)
- void incrementalZeroTest (Ctxt *res[ ], const EncryptedArray &ea, const Ctxt &ctxt, long n)
- void RelaxedInv (NTL::Mat< NTL::zz_p > &x, const NTL::Mat< NTL::zz_p > &a)
- void RelaxedInv (NTL::Mat< NTL::GF2 > &x, const NTL::Mat< NTL::GF2 > &a)
- void TraceMap (NTL::GF2X &w, const NTL::GF2X &a, long d, const NTL::GF2XModulus &F, const NTL::GF2X &b)
- template void getHyperColumn (NTL::Vec< long > &v, const ConstCubeSlice< long > &s, long pos)
- template void setHyperColumn (const NTL::Vec< long > &v, const CubeSlice< long > &s, long pos)
- template void setHyperColumn (const NTL::Vec< long > &v, const CubeSlice< long > &s, long pos, const long &val)
- template void print3D (const HyperCube< long > &c)
- template void getHyperColumn (NTL::Vec< NTL::zz_p > &v, const ConstCubeSlice< NTL::zz_p > &s, long pos)
- template void setHyperColumn (const NTL::Vec< NTL::zz_p > &v, const CubeSlice< NTL::zz_p > &s, long pos)
- template void setHyperColumn (const NTL::Vec< NTL::zz_p > &v, const CubeSlice< NTL::zz_p > &s, long pos, const NTL::zz_p &val)
- template void print3D (const HyperCube< NTL::zz_p > &c)
- std::ostream & operator<< (std::ostream &str, const PubKey &pk)
- std::istream & operator>> (std::istream &str, PubKey &pk)
- std::ostream & operator<< (std::ostream &str, const SecKey &sk)
- std::istream & operator>> (std::istream &str, SecKey &sk)
- void printFlow (FlowGraph &fg)
- std::shared_ptr< GeneralAutomorphPrecon > buildGeneralAutomorphPrecon (const Ctxt &ctxt, long dim, const EncryptedArray &ea)
- template<typename RX >
  std::shared_ptr< ConstMultiplier > build_ConstMultiplier (const RX &poly)
- template<typename RX , typename type >
  std::shared_ptr< ConstMultiplier > build_ConstMultiplier (const RX &poly, long dim, long amt, const EncryptedArrayDerived< type > &ea)
- void MulAdd (Ctxt &x, const std::shared_ptr< ConstMultiplier > &a, const Ctxt &b)
- void DestMulAdd (Ctxt &x, const std::shared_ptr< ConstMultiplier > &a, Ctxt &b)

- void GenBabySteps (std::vector< std::shared_ptr< Ctxt >> &v, const Ctxt &ctxt, long dim, bool clean)
- template<typename zp , typename zz >
  void FindPrimRootT (zp &root, unsigned long e)
- template bool intVecCRT (NTL::vec_ZZ &, const NTL::ZZ &, const NTL::vec_ZZ &, long)
- template bool intVecCRT (NTL::vec_ZZ &, const NTL::ZZ &, const NTL::vec_long &, long)
- template bool intVecCRT (NTL::vec_ZZ &, const NTL::ZZ &, const NTL::Vec< NTL::zz_p > &, long)
- void removeDups (std::list< long > &x, bool ∗aux)
- void addOffset (std::list< long > &x, long offset, long n, bool ∗aux, UNUSED bool good=false)
- long reducedCount (const std::list< long > &x, long n, bool ∗aux)
- void buildBenesCostTable (long n, long k, bool good, NTL::Vec< NTL::Vec< long >> &tab)
- std::ostream & operator<< (std::ostream &s, LongNodePtr p)
- BenesMemoEntry optimalBenesAux (long i, long budget, long nlev, const NTL::Vec< NTL::Vec< long >> &costTab, BenesMemoTable &memoTab)
- void optimalBenes (long n, long budget, bool good, long &cost, LongNodePtr &solution)
- void print (std::ostream &s, SplitNodePtr p, bool first)
- std::ostream & operator<< (std::ostream &s, SplitNodePtr p)
- long length (GenNodePtr ptr)
- std::ostream & operator<< (std::ostream &s, GenNodePtr p)
- LowerMemoEntry optimalLower (long order, bool good, long budget, long mid, LowerMemoTable &lower↩ MemoTable)
- UpperMemoEntry optimalUpperAux (const NTL::Vec< GenDescriptor > &vec, long i, long budget, long mid, UpperMemoTable &upperMemoTable, LowerMemoTable &lowerMemoTable)
- template<typename RX >
  bool poly_comp (const RX &a, const RX &b)
- bool less_than (NTL::GF2 a, NTL::GF2 b)
- bool less_than (NTL::zz_p a, NTL::zz_p b)
- bool less_than (const NTL::GF2X &a, const NTL::GF2X &b)
- bool less_than (const NTL::zz_pX &a, const NTL::zz_pX &b)
- bool less_than (const NTL::GF2E &a, const NTL::GF2E &b)
- bool less_than (const NTL::zz_pE &a, const NTL::zz_pE &b)
- bool less_than (const NTL::GF2EX &a, const NTL::GF2EX &b)
- bool less_than (const NTL::zz_pEX &a, const NTL::zz_pEX &b)
- bool comparePAlgebra (const PAlgebra &palg, unsigned long m, unsigned long p, UNUSED unsigned long r, const std::vector< long > &gens, const std::vector< long > &ords)
- template<typename T >
  void PAlgebraLift (const NTL::ZZX &phimx, const T &lfactors, T &factors, T &crtc, long r)
- void EDF (NTL::vec_zz_pX &v, const NTL::zz_pX &f, long d)
- NTL::zz_pEX FrobeniusMap (const NTL::zz_pEXModulus &F)
- void InvModpr (NTL::zz_pX &S, const NTL::zz_pX &F, const NTL::zz_pX &G, long p, long r)
- template<> void PAlgebraLift (const NTL::ZZX &phimx, const NTL::vec_zz_pX &lfactors, NTL::vec_zz_pX &factors, NTL::vec_zz_pX &crtc, long r)
- std::ostream & operator<< (std::ostream &s, const PermNetwork &net)
- template void applyPermToVec< long > (NTL::Vec< long > &out, const NTL::Vec< long > &in, const Permut &p1)
- template void applyPermToVec< long > (std::vector< long > &out, const std::vector< long > &in, const Permut &p1)
- template void applyPermToVec< NTL::ZZX > (std::vector< NTL::ZZX > &out, const std::vector< NTL::ZZX > &in, const Permut &p1)
- template void applyPermsToVec< long > (NTL::Vec< long > &out, const NTL::Vec< long > &in, const Permut &p2, const Permut &p1)
- template void applyPermsToVec< long > (std::vector< long > &out, const std::vector< long > &in, const Permut &p2, const Permut &p1)
- void breakPermTo3 (const HyperCube< long > &pi, long dim, ColPerm &rho1, HyperCube< long > &rho2, ColPerm &rho3)
- void ComputeOneGenMapping (Permut &genMap, const OneGeneratorTree &T)

to a single generator tree

- std::ostream & operator<< (std::ostream &s, const SubDimension &sd)
- std::ostream & operator<< (std::ostream &s, const GeneratorTrees &trees)
- std::istream & operator>> (std::istream &is, PolyMod &poly)
- std::ostream & operator<< (std::ostream &os, const PolyMod &poly)
- std::ostream & operator<< (std::ostream &os, const PolyModRing &ring)
- void computeDivVec (NTL::Vec< long > &divVec, long m, const NTL::Vec< long > &powVec)
- void computeInvVec (NTL::Vec< long > &invVec, const NTL::Vec< long > &divVec, const NTL::Vec< long > &powVec)
- bool operator> (const ModuliSizes::Entry &a, const ModuliSizes::Entry &b)
- std::ostream & operator<< (std::ostream &s, const ModuliSizes &szs)
- std::istream & operator>> (std::istream &s, ModuliSizes &szs)
- void addSmallPrimes (Context &context, long resolution, long cpSize)

  Add small primes to get target resolution.
- long ctxtPrimeSize (long nBits)
- void addCtxtPrimes (Context &context, long nBits, long targetSize)
- template<typename Scheme >
  Scheme::SlotType randomSlot (const Context &context)
- template<> BGV::SlotType randomSlot< BGV > (const Context &context)
- template<> CKKS::SlotType randomSlot< CKKS > (UNUSED const Context &context)
- void extractDigitsPacked (Ctxt &ctxt, long botHigh, long r, long ePrime, const std::vector< NTL::ZZX > &unpackSlotEncoding)
- void extractDigitsThin (Ctxt &ctxt, long botHigh, long r, long ePrime)
- double boundRoundingNoise (UNUSED long m, long phim, long p2r, double epsilon)
- bool timer_compare (const FHEtimer *a, const FHEtimer *b)

Variables

- Context * activeContext = nullptr
- SecKey * dbgKey = nullptr
- std::shared_ptr< const EncryptedArray > dbgEa = nullptr
- NTL::ZZX dbg_ptxt
- bool fhe_stats = false
- int fhe_test_force_bsgs = 0
- int fhe_test_force_hoist = 0
- const long double PI
- const double erfc_inverse [ ]
- long thinRecrypt_initial_level
- long fhe_force_chen_han = 0
- long printFlag
- NTL_THREAD_LOCAL bool replicateVerboseFlag = false
- int fhe_watcher = 0
- const unsigned long CLOCK_SCALE = (unsigned long)CLOCKS_PER_SEC

Strategies for generating key-switching matrices

These functions are implemented in KeySwitching.cpp

- long KSGiantStepSize (long D)

  Function that returns number of baby steps. Used to keep this and matmul routines "in sync".
- void addAllMatrices (SecKey &sKey, long keyID=0)

Maximalistic approach: generate matrices s(X^e)->s(X) for all e in Zm.*

- void addFewMatrices (SecKey &sKey, long keyID=0)

  Generate matrices so every s(X^e) can be reLinearized in at most two steps.

- void addSome1DMatrices (SecKey &sKey, long bound=HELIB_KEYSWITCH_THRESH, long keyID=0)

  *Generate some matrices of the form s(X^{g^i})->s(X), but not all. For a generator g whose order is larger than bound, generate only enough matrices for the giant-step/baby-step procedures (2*sqrt(ord(g))of them).*

- void add1DMatrices (SecKey &sKey, long keyID=0)

  Generate all matrices s(X^{g^i})->s(X) for generators g of Zm /(p) and i<ord(g). If g has different orders in Zm* and Zm* /(p) then generate also matrices of the form s(X^{g^{-i}})->s(X)*

- void addBSGS1DMatrices (SecKey &sKey, long keyID=0)
- void addSomeFrbMatrices (SecKey &sKey, long bound=HELIB_KEYSWITCH_THRESH, long keyID=0)

  Generate all/some Frobenius matrices of the form s(X^{p^i})->s(X)

- void addFrbMatrices (SecKey &sKey, long keyID=0)
- void addBSGSFrbMatrices (SecKey &sKey, long keyID=0)
- void addMinimal1DMatrices (SecKey &sKey, long keyID=0)

  These routines just add a single matrix (or two, for bad dimensions)

- void addMinimalFrbMatrices (SecKey &sKey, long keyID=0)
- void addMatrices4Network (SecKey &sKey, const PermNetwork &net, long keyID=0)
- void addTheseMatrices (SecKey &sKey, const std::set< long > &automVals, long keyID=0)

  Generate specific key-switching matrices, described by the given set.

- void PolyRed (NTL::ZZX &out, const NTL::ZZX &in, long q, bool abs=false)

  Reduce all the coefficients of a polynomial modulo q.

- void PolyRed (NTL::ZZX &out, const NTL::ZZX &in, const NTL::ZZ &q, bool abs=false)
- void PolyRed (NTL::ZZX &F, long q, bool abs=false)
- void PolyRed (NTL::ZZX &F, const NTL::ZZ &q, bool abs=false)
- void vecRed (NTL::Vec< NTL::ZZ > &out, const NTL::Vec< NTL::ZZ > &in, long q, bool abs)
- void vecRed (NTL::Vec< NTL::ZZ > &out, const NTL::Vec< NTL::ZZ > &in, const NTL::ZZ &q, bool abs)

Some enhanced conversion routines

- void convert (long &x1, const NTL::GF2X &x2)
- void convert (long &x1, const NTL::zz_pX &x2)
- void convert (NTL::vec_zz_pE &X, const std::vector< NTL::ZZX > &A)
- void convert (NTL::mat_zz_pE &X, const std::vector< std::vector< NTL::ZZX >> &A)
- void convert (std::vector< NTL::ZZX > &X, const NTL::vec_zz_pE &A)
- void convert (std::vector< std::vector< NTL::ZZX >> &X, const NTL::mat_zz_pE &A)
- void convert (NTL::Vec< long > &out, const NTL::ZZX &in)
- void convert (NTL::Vec< long > &out, const NTL::zz_pX &in, bool symmetric=true)
- void convert (NTL::Vec< long > &out, const NTL::GF2X &in)
- void convert (NTL::ZZX &out, const NTL::Vec< long > &in)
- void convert (NTL::GF2X &out, const NTL::Vec< long > &in)

- double boundFreshNoise (long m, long phim, double sigma, double epsilon=9e-13)
- double boundRoundingNoise (long m, long phim, long p2r, double epsilon=9e-13)

6.2.1 Typedef Documentation

6.2.1.1 aligned_vector

```
template<class T >
using helib::aligned_vector = typedef PGFFT::aligned_vector<T>
```

6.2.1.2 cmplx_t

```
typedef complex<double> helib::cmplx_t
```

6.2.1.3 CtPtrMat

```
typedef PtrMatrix<Ctxt> helib::CtPtrMat
```

6.2.1.4 CtPtrMat_ptVecCt

```
typedef PtrMatrix_ptVec<Ctxt> helib::CtPtrMat_ptVecCt
```

6.2.1.5 CtPtrMat_ptvectorCt

```
typedef PtrMatrix_ptvector<Ctxt> helib::CtPtrMat_ptvectorCt
```

6.2.1.6 CtPtrMat_VecCt

```
typedef PtrMatrix_Vec<Ctxt> helib::CtPtrMat_VecCt
```

6.2.1.7 CtPtrMat_vectorCt

```
typedef PtrMatrix_vector<Ctxt> helib::CtPtrMat_vectorCt
```

6.2.1.8 CtPtrs

```
typedef PtrVector<Ctxt> helib::CtPtrs
```

6.2.1.9 CtPtrs_slice

```
typedef PtrVector_slice<Ctxt> helib::CtPtrs_slice
```

6.2.1.10 CtPtrs_VecCt

```
typedef PtrVector_VecT<Ctxt> helib::CtPtrs_VecCt
```

6.2.1.11 CtPtrs_VecPt

```
typedef PtrVector_VecPt<Ctxt> helib::CtPtrs_VecPt
```

6.2.1.12 CtPtrs_vectorCt

```
typedef PtrVector_vectorT<Ctxt> helib::CtPtrs_vectorCt
```

6.2.1.13 CtPtrs_vectorPt

```
typedef PtrVector_vectorPt<Ctxt> helib::CtPtrs_vectorPt
```

6.2.1.14 cx_double

```
typedef std::complex< double > helib::cx_double
```

6.2.1.15 DCRTptr

```
typedef std::shared_ptr<DoubleCRT> helib::DCRTptr
```

6.2.1.16 FlowGraph

```
typedef std::vector<FNeighborList> helib::FlowGraph
```

6.2.1.17 FNeighborList

```
typedef std::unordered_map<long, FlowEdge> helib::FNeighborList
```

6.2.1.18 ldbl

```
typedef long double helib::ldbl
```

6.2.1.19 LNeighborList

```
typedef std::unordered_multimap<long, LabeledEdge> helib::LNeighborList
```

6.2.1.20 LONG

```
typedef long helib::LONG
```

6.2.1.21 NodeIdx

```
typedef std::pair<long, long> helib::NodeIdx
```

6.2.1.22 OneGeneratorTree

```
typedef FullBinaryTree<SubDimension> helib::OneGeneratorTree
```

6.2.1.23 Permut

```
typedef NTL::Vec<long> helib::Permut
```

A simple permutation is just a vector with p[i]=\pi_i.

6.2.1.24 zzX

```
typedef NTL::Vec<long> helib::zzX
```

6.2.1.25 ZZXptr

```
typedef std::shared_ptr<NTL::ZZX> helib::ZZXptr
```

6.2.2 Enumeration Type Documentation

6.2.2.1 PA_tag

```
enum helib::PA_tag
```

Enumerator

PA_GF2_tag	
PA_zz_p_tag	
PA_cx_tag	

6.2.3 Function Documentation

6.2.3.1 add() [1/3]

```
void helib::add (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            const PlaintextArray & other )
```

6.2.3.2 add() [2/3]

```
void helib::add (
            std::vector< NTL::ZZX > & x,
            const std::vector< NTL::ZZX > & a,
            const std::vector< NTL::ZZX > & b )
```

6.2.3.3 add() [3/3]

```
void helib::add (
            zzX & res,
            const zzX & a,
            const zzX & b )
```

6.2.3.4 add1DMatrices()

```
void helib::add1DMatrices (
            SecKey & sKey,
            long keyID = 0 )
```

Generate all matrices s(X^{g^i})->s(X) for generators g of Zm∗ /(p) and i<ord(g). If g has different orders in Zm∗ and Zm∗ /(p) then generate also matrices of the form s(X^{g^{-i}})->s(X)

6.2.3.5 addAllMatrices()

```
void helib::addAllMatrices (
            SecKey & sKey,
            long keyID = 0 )
```

Maximalistic approach: generate matrices s(X^e)->s(X) for all e in Zm∗.

6.2.3.6 addBSGS1DMatrices()

```
void helib::addBSGS1DMatrices (
            SecKey & sKey,
            long keyID = 0 )
```

6.2.3.7 addBSGSFrbMatrices()

```
void helib::addBSGSFrbMatrices (
            SecKey & sKey,
            long keyID = 0 )
```

6.2.3.8 addCtxtPrimes()

```
void helib::addCtxtPrimes (
            Context & context,
            long nBits,
            long targetSize )
```

6.2.3.9 addFewMatrices()

```
void helib::addFewMatrices (
            SecKey & sKey,
            long keyID = 0 )
```

Generate matrices so every s(X^e) can be reLinearized in at most two steps.

6.2.3.10 addFrbMatrices()

```
void helib::addFrbMatrices (
            SecKey & sKey,
            long keyID = 0 )
```

6.2.3.11 addManyNumbers()

```
void helib::addManyNumbers (
            CtPtrs & sum,
            CtPtrMat & numbers,
            long sizeLimit = 0,
            std::vector< zzX > * unpackSlotEncoding = nullptr )
```

Sum an arbitrary amount of numbers in binary representation.

Parameters

sum	result of the summation.
numbers	values of which to sum.
sizeLimit	number of bits to compute on, taken from the least significant end.
unpackSlotEncoding	vector of constants for unpacking, as used in bootstrapping.

Calculates the sum of many numbers using the 3-for-2 method.

6.2.3.12 addMatrices4Network()

```
void helib::addMatrices4Network (
            SecKey & sKey,
            const PermNetwork & net,
            long keyID = 0 )
```

6.2.3.13 addMinimal1DMatrices()

```
void helib::addMinimal1DMatrices (
            SecKey & sKey,
            long keyID = 0 )
```

These routines just add a single matrix (or two, for bad dimensions)

6.2.3.14 addMinimalFrbMatrices()

```
void helib::addMinimalFrbMatrices (
            SecKey & sKey,
            long keyID = 0 )
```

6.2.3.15 addOffset()

```
void helib::addOffset (
            std::list< long > & x,
            long offset,
            long n,
            bool * aux,
            UNUSED bool good = false )
```

6.2.3.16 addSmallPrimes()

```
void helib::addSmallPrimes (
            Context & context,
            long resolution,
            long cpSize )
```

Add small primes to get target resolution.

6.2.3.17 addSome1DMatrices()

```
void helib::addSome1DMatrices (
            SecKey & sKey,
            long bound = HELIB_KEYSWITCH_THRESH,
            long keyID = 0 )
```

Generate some matrices of the form s(X^{g^i})->s(X), but not all. For a generator g whose order is larger than bound, generate only enough matrices for the giant-step/baby-step procedures (2∗sqrt(ord(g))of them).

6.2.3.18 addSomeFrbMatrices()

```
void helib::addSomeFrbMatrices (
            SecKey & sKey,
            long bound = HELIB_KEYSWITCH_THRESH,
            long keyID = 0 )
```

Generate all/some Frobenius matrices of the form s(X^{p^i})->s(X)

6.2.3.19 addSomePrimes()

```
void helib::addSomePrimes (
            Ctxt & c )
```

6.2.3.20 addTheseMatrices()

```
void helib::addTheseMatrices (
            SecKey & sKey,
            const std::set< long > & automVals,
            long keyID = 0 )
```

Generate specific key-switching matrices, described by the given set.

6.2.3.21 addTwoNumbers()

```
void helib::addTwoNumbers (
            CtPtrs & sum,
            const CtPtrs & lhs,
            const CtPtrs & rhs,
            long sizeLimit = 0,
            std::vector< zzX > * unpackSlotEncoding = nullptr )
```

Adds two numbers in binary representation where each ciphertext of the input vector contains a bit.

Add two integers in binary representation.

Parameters

sum	result of the addition operation.
lhs	left hand side of the addition.
rhs	right hand side of the addition.

Parameters

sizeLimit	number of bits to compute on, taken from the least significant end.
unpackSlotEncoding	vector of constants for unpacking, as used in bootstrapping.

6.2.3.22 applyLinPoly() [1/2]

```
void helib::applyLinPoly (
            NTL::GF2E & beta,
            const NTL::vec_GF2E & C,
            const NTL::GF2E & alpha,
            long p )
```

A version for GF2: must be called with p == 2 and r == 1.

6.2.3.23 applyLinPoly() [2/2]

```
void helib::applyLinPoly (
            NTL::zz_pE & beta,
            const NTL::vec_zz_pE & C,
            const NTL::zz_pE & alpha,
            long p )
```

Apply a linearized polynomial with coefficient vector C.

NTL's current smallint modulus, zz_p::modulus(), is assumed to be p^r, for p prime, r >= 1 integer.

6.2.3.24 applyLinPoly1()

```
void helib::applyLinPoly1 (
            const EncryptedArray & ea,
            Ctxt & ctxt,
            const std::vector< NTL::ZZX > & C )
```

6.2.3.25 applyLinPolyLL() [1/4]

```
template void helib::applyLinPolyLL (
            Ctxt & ctxt,
            const std::vector< DoubleCRT > & encodedC,
            long d )
```

6.2.3.26 applyLinPolyLL() [2/4]

```
template void helib::applyLinPolyLL (
            Ctxt & ctxt,
            const std::vector< NTL::ZZX > & encodedC,
            long d )
```

6.2.3.27 applyLinPolyLL() [3/4]

```
template<typename P >
void helib::applyLinPolyLL (
            Ctxt & ctxt,
            const std::vector< P > & encodedC,
            long d )
```

6.2.3.28 applyLinPolyLL() [4/4]

```
template void helib::applyLinPolyLL (
            Ctxt & ctxt,
            const std::vector< zzX > & encodedC,
            long d )
```

6.2.3.29 applyLinPolyMany()

```
void helib::applyLinPolyMany (
            const EncryptedArray & ea,
            Ctxt & ctxt,
            const std::vector< std::vector< NTL::ZZX >> & Cvec )
```

6.2.3.30 applyPerm()

```
void helib::applyPerm (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            const NTL::Vec< long > & pi )
```

6.2.3.31 applyPermsToVec() [1/2]

```
template<typename T >
void helib::applyPermsToVec (
            NTL::Vec< T > & out,
            const NTL::Vec< T > & in,
            const Permut & p2,
            const Permut & p1 )
```

Apply two permutations to a std::vector out[i]=in[p2[p1[i]]] (NOT in-place)

6.2.3.32 applyPermsToVec() [2/2]

```
template<typename T >
void helib::applyPermsToVec (
            std::vector< T > & out,
            const std::vector< T > & in,
            const Permut & p2,
            const Permut & p1 )
```

6.2.3.33 applyPermsToVec< long >() [1/2]

```
template void helib::applyPermsToVec< long > (
            NTL::Vec< long > & out,
            const NTL::Vec< long > & in,
            const Permut & p2,
            const Permut & p1 )
```

6.2.3.34 applyPermsToVec< long >() [2/2]

```
template void helib::applyPermsToVec< long > (
            std::vector< long > & out,
            const std::vector< long > & in,
            const Permut & p2,
            const Permut & p1 )
```

6.2.3.35 applyPermToVec() [1/2]

```
template<typename T >
void helib::applyPermToVec (
            NTL::Vec< T > & out,
            const NTL::Vec< T > & in,
            const Permut & p1 )
```

Apply a permutation to a std::vector, out[i]=in[p1[i]] (NOT in-place)

6.2.3.36 applyPermToVec() [2/2]

```
template<typename T >
void helib::applyPermToVec (
            std::vector< T > & out,
            const std::vector< T > & in,
            const Permut & p1 )
```

6.2.3.37 applyPermToVec< long >() [1/2]

```
template void helib::applyPermToVec< long > (
            NTL::Vec< long > & out,
            const NTL::Vec< long > & in,
            const Permut & p1 )
```

6.2.3.38 applyPermToVec< long >() [2/2]

```
template void helib::applyPermToVec< long > (
            std::vector< long > & out,
            const std::vector< long > & in,
            const Permut & p1 )
```

6.2.3.39 applyPermToVec< NTL::ZZX >()

```
template void helib::applyPermToVec< NTL::ZZX > (
            std::vector< NTL::ZZX > & out,
            const std::vector< NTL::ZZX > & in,
            const Permut & p1 )
```

6.2.3.40 areTimersOn()

```
bool helib::areTimersOn ( )  [inline]
```

6.2.3.41 argmax() [1/2]

```
long helib::argmax (
            std::vector< long > & v,
            bool(*)(long, long) moreThan )  [inline]
```

A variant with a specialized comparison function (∗moreThan)(a,b) returns the comparison a>b.

6.2.3.42 argmax() [2/2]

```
template<typename T >
long helib::argmax (
            std::vector< T > & v )
```

6.2.3.43 argmin()

```
template<typename T >
long helib::argmin (
            std::vector< T > & v )
```

6.2.3.44 argminmax()

```
template<typename T , bool maxFlag>
long helib::argminmax (
            std::vector< T > & v )
```

Find the index of the (first) largest/smallest element.

These procedures are roughly just simpler variants of std::max_element and std::min_element. argmin/argmax are implemented as a template, so the code must be placed in the header file for the compiler to find it. The class T must have an implementation of operator> and operator< for this template to work.

Template Parameters

maxFlag	A boolean value: true - argmax, false - argmin

6.2.3.45 assertEq()

```
template<typename ExceptionTy = ::helib::LogicError, typename T = void>
void helib::assertEq (
            const T & a,
            const T & b,
            const std::string & message ) [inline]
```

Function throwing an exception of type ExceptionTy if the two arguments are not equal.

Template Parameters

ExceptionTy	type of the exception thrown.
T	type of the elements to be compared.

Parameters

a	the first element to be compared.
b	the second element to be compared.
message	the message of the exception raised if the two values are not equal.

Exceptions

ExceptionTy	exception if the two values are not equal.

Note

ExceptionTy first and T defaulted to void so that one can specify only ExceptionTy, letting T be inferred from the argument passed.

6.2.3.46 assertFalse()

```
template<typename ExceptionTy = ::helib::LogicError, typename T = void>
void helib::assertFalse (
            T value,
            const std::string & message )  [inline]
```

Function throwing an exception of type ExceptionTy if the condition is true.

Template Parameters

ExceptionTy	type of the exception thrown.
T	type of the condition being checked (must be a bool).

Parameters

value	the condition being checked.
message	the message of the exception raised if the condition is true.

Exceptions

ExceptionTy	exception if condition is true.

Note

ExceptionTy first and T defaulted to void so that one can specify only ExceptionTy, letting T be inferred from the argument passed.

6.2.3.47 assertInRange()

```
template<typename ExceptionTy = ::helib::OutOfRangeError, typename T = void>
void helib::assertInRange (
            const T & elem,
            const T & min,
            const T & max,
            const std::string & message,
            bool right_inclusive = false )  [inline]
```

Function throwing an exception of type ExceptionTy if the element is in the range [min,max) or [min, max]

Template Parameters

ExceptionTy	type of the exception thrown.
T	type of the element (and of the range).

Parameters

elem	the element to be tested.
min	the left side of the range (always inclusive).
max	the right side of the range (default exclusive).
message	the message of the exception raised if the element is not in the range.

Parameters

right_inclusive	flag specifying if the right side is inclusive (default false).

Exceptions

ExceptionTy	exception if elem is not in the range

Note

ExceptionTy first and T defaulted to void so that one can specify only ExceptionTy, letting T be inferred from the argument passed.

6.2.3.48 assertNeq()

```
template<typename ExceptionTy = ::helib::LogicError, typename T = void>
void helib::assertNeq (
            const T & a,
            const T & b,
            const std::string & message )  [inline]
```

Function throwing an exception of type ExceptionTy if the two arguments are equal.

Template Parameters

ExceptionTy	type of the exception thrown.
T	type of the elements to be compared.

Parameters

a	the first element to be compared.

Parameters

b	the second element to be compared.
message	the message of the exception raised if the two values are equal.

Exceptions

ExceptionTy	exception if the two values are equal.

Note

ExceptionTy first and T defaulted to void so that one can specify only ExceptionTy, letting T be inferred from the argument passed.

6.2.3.49 assertNotNull()

```
template<typename ExceptionTy = ::helib::LogicError, typename T = void>
void helib::assertNotNull (
            const T & p,
            const std::string & message )  [inline]
```

Function throwing an exception of type ExceptionTy if the argument is nullptr.

Template Parameters

ExceptionTy	type of the exception thrown.
T	type of the element.

Parameters

p	the element to be tested.
message	the message of the exception raised if the element is nullptr.

Exceptions

ExceptionTy	exception if p is nullptr.

Note

ExceptionTy first and T defaulted to void so that one can specify only ExceptionTy, letting T be inferred from the argument passed.

6.2.3.50 assertTrue()

```
template<typename ExceptionTy = ::helib::LogicError, typename T = void>
void helib::assertTrue (
            const T & value,
            const std::string & message )  [inline]
```

Function throwing an exception of type ExceptionTy if the condition is false.

Template Parameters

ExceptionTy	type of the exception thrown.
T	type of the condition being checked (must be a bool).

Parameters

value	the condition being checked.

Parameters

message	the message of the exception raised if the condition is false.

Exceptions

ExceptionTy	exception if condition is false.

Note

ExceptionTy first and T defaulted to void so that one can specify only ExceptionTy, letting T be inferred from the argument passed.

6.2.3.51 atoVec()

```
template<typename T >
NTL::Vec<T> helib::atoVec (
            const char * a )
```

6.2.3.52 atovector()

```
template<typename T >
std::vector<T> helib::atovector (
            const char * a )
```

6.2.3.53 balanced_MulMod()

```
void helib::balanced_MulMod (
            NTL::ZZX & out,
            const NTL::ZZX & f,
            long a,
            long q )
```

Multiply the polynomial f by the integer a modulo q output coefficients are balanced (appropriately randomized for even q)

6.2.3.54 balanced_zzX() [1/2]

```
zzX helib::balanced_zzX (
            const NTL::GF2X & f )
```

6.2.3.55 balanced_zzX() [2/2]

```
zzX helib::balanced_zzX (
            const NTL::zz_pX & f )
```

6.2.3.56 balRem()

```
long helib::balRem (
            long a,
            long q )  [inline]
```

Return balanced remainder. Assumes a in [0, q) and returns balanced remainder in (-q/2, q/2]

6.2.3.57 binaryCond()

```
void helib::binaryCond (
            CtPtrs & output,
            const Ctxt & cond,
            const CtPtrs & trueValue,
            const CtPtrs & falseValue )
```

Implementation of `output = cond * trueValue + (1 - cond) * falseValue`.

Implementation of output = cond ? trueValue : falseValue.

Parameters

output	Equal to `trueValue` in slots where `cond` is one and `falseValue` in slots where `cond` is zero.

Parameters

cond	The condition, namely a `Ctxt` containing elements of {0,1} in each slot.
trueValue	Value of `output` wherever `cond` is one.
falseValue	Value of `output` wherever `cond` is zero.

Note

`trueValue`, `falseValue` and `output` must have the same size.

6.2.3.58 binaryMask()

```
void helib::binaryMask (
            CtPtrs & binaryNums,
            const Ctxt & mask )
```

Zeroes the slots of `binaryNums` where the corresponding slot of `mask` is 0.

Apply mask across the vector of bits slot-wise.

Parameters

binaryNums	Input bits on which to mask (this is done in place).
mask	Encrypted mask indicating desired slots.

6.2.3.59 bitSetToLong()

```
long helib::bitSetToLong (
            long bits,
            long bitSize )
```

Considers `bits` as a vector of bits and returns the value it represents when interpreted as a n-bit 2's complement number, where n is given by `bitSize`.

Parameters

bits	The value containing the bits to be reinterpreted.
bitSize	The number of bits to use, taken from the least significant end of `bits`.

Returns

The value of the reinterpreted number as a long.

6.2.3.60 bitwiseAnd() [1/2]

```
void helib::bitwiseAnd (
            CtPtrs & output,
            const CtPtrs & input,
            const std::vector< long > mask )
```

Compute a bitwise AND between `input` and a `std::vector<long>`.

Compute a bitwise AND between `input` and `mask`.

Parameters

output	Equal to the output of the AND operation.
input	Number to A↩ ND.
mask	Number to A↩ ND with `input`. This should be a vector of elements of {0,1}.

Note

The size of `output` and `input` must be the same.

6.2.3.61 bitwiseAnd() [2/2]

```
void helib::bitwiseAnd (
            CtPtrs & output,
```

```
const CtPtrs & lhs,
const CtPtrs & rhs )
```

Compute a bitwise AND between `lhs` and `rhs`.

Parameters

output	Result of bitwise `lhs` AND `rhs`.
lhs	Left operand to the AND operation.
rhs	Right operand to the AND operation.

Note

`output`, `lhs` and `rhs` must all have the same size.

6.2.3.62 bitwiseNot()

```
void helib::bitwiseNot (
            CtPtrs & output,
            const CtPtrs & input )
```

Compute a bitwise NOT of `input`.

Parameters

output	Result of bit-flipping `input`.
input	Binary number to be bit-flipped.

Note

The size of `output` and `input` must be the same.

6.2.3.63 bitwiseOr()

```
void helib::bitwiseOr (
            CtPtrs & output,
            const CtPtrs & lhs,
            const CtPtrs & rhs )
```

Compute a bitwise OR between `lhs` and `rhs`.

Parameters

output	Result of bitwise `lhs` OR `rhs`.
lhs	Left operand to the OR operation.
rhs	Right operand to the OR operation.

Note

`output`, `lhs` and `rhs` must all have the same size.

6.2.3.64 bitwiseRotate()

```
void helib::bitwiseRotate (
            CtPtrs & output,
            const CtPtrs & input,
            long rotamt )
```

Rotate `input` by `rotamt`.

Rotate binary numbers by `rotamt`.

Parameters

output	Rotated result.
input	The number to be bitwise-rotated.

Parameters

rotamt	The amount by which to rotate `input`. May be negative for opposite-direction rotations.

Note

For positive `rotamt` arguments, this rotates towards the most-significant end (i.e. the same direction as leftBitwiseShift).

The size of `output` and `input` must be the same.

6.2.3.65 bitwiseXOR()

```
void helib::bitwiseXOR (
            CtPtrs & output,
            const CtPtrs & lhs,
            const CtPtrs & rhs )
```

Compute a bitwise XOR between `lhs` and `rhs`.

Parameters

output	Result of bitwise `lhs` XOR `rhs`.
lhs	Left operand to the XOR operation.
rhs	Right operand to the XOR operation.

Note

`output`, `lhs` and `rhs` must all have the same size.

6.2.3.66 BluesteinFFT() [1/2]

```
void helib::BluesteinFFT (
            NTL::zz_pX & x,
            long n,
            const NTL::zz_p & root,
            const NTL::zz_pX & powers,
            const NTL::Vec< NTL::mulmod_precon_t > & powers_aux,
            const NTL::fftRep & Rb )
```

apply bluestein

6.2.3.67 BluesteinFFT() [2/2]

```
void helib::BluesteinFFT (
            NTL::zz_pX & x,
            long n,
            UNUSED const NTL::zz_p & root,
            const NTL::zz_pX & powers,
            const NTL::Vec< NTL::mulmod_precon_t > & powers_aux,
            const NTL::fftRep & Rb )
```

6.2.3.68 BluesteinInit()

```
void helib::BluesteinInit (
            long n,
            const NTL::zz_p & root,
            NTL::zz_pX & powers,
            NTL::Vec< NTL::mulmod_precon_t > & powers_aux,
            NTL::fftRep & Rb )
```

initialize bluestein

6.2.3.69 boundFreshNoise()

```
double helib::boundFreshNoise (
            long m,
            long phim,
            double sigma,
            double epsilon = 9e-13 )
```

Helper functions, return a bound B such that for random noise terms we have Pr[|canonicalEmbed(noise)|_{\infty} > B] < epsilon. (The default is epsilon = 2^{-40}.)

6.2.3.70 boundRoundingNoise() [1/2]

```
double helib::boundRoundingNoise (
            long m,
            long phim,
            long p2r,
            double epsilon = 9e-13 )
```

6.2.3.71 boundRoundingNoise() [2/2]

```
double helib::boundRoundingNoise (
            UNUSED long m,
            long phim,
            long p2r,
            double epsilon )
```

6.2.3.72 breakPermByDim()

```
void helib::breakPermByDim (
            std::vector< ColPerm > & out,
            const Permut & pi,
            const CubeSignature & sig )
```

Takes a permutation pi over m-dimensional cube C=Z_{n1} x...x Z_{nm} and expresses pi as a product pi = rho_{2m-1} o ... o rho_2 o rho_1 where each rho_i is a column permutation along one dimension. Specifically for i<m, the permutations rho_i and rho_{2(m-1)-i} permute the i'th dimension.

6.2.3.73 breakPermTo3()

```
void helib::breakPermTo3 (
            const HyperCube< long > & pi,
            long dim,
            ColPerm & rho1,
            HyperCube< long > & rho2,
            ColPerm & rho3 )
```

6.2.3.74 build_ConstMultiplier() [1/2]

```
template<typename RX >
std::shared_ptr<ConstMultiplier> helib::build_ConstMultiplier (
            const RX & poly )
```

6.2.3.75 build_ConstMultiplier() [2/2]

```
template<typename RX , typename type >
std::shared_ptr<ConstMultiplier> helib::build_ConstMultiplier (
            const RX & poly,
            long dim,
            long amt,
            const EncryptedArrayDerived< type > & ea )
```

6.2.3.76 buildBenesCostTable()

```
void helib::buildBenesCostTable (
            long n,
            long k,
            bool good,
            NTL::Vec< NTL::Vec< long >> & tab )
```

6.2.3.77 BuildContext()

```
NTL::zz_pContext helib::BuildContext (
            long p,
            long maxroot )
```

6.2.3.78 buildContextFromAscii()

```
std::unique_ptr< Context > helib::buildContextFromAscii (
            std::istream & str )
```

6.2.3.79 buildContextFromBinary()

```
std::unique_ptr< Context > helib::buildContextFromBinary (
            std::istream & str )
```

6.2.3.80 buildEncryptedArray()

```
EncryptedArrayBase * helib::buildEncryptedArray (
            const Context & context,
            const PAlgebraMod & alMod,
            const NTL::ZZX & G = NTL::ZZX::zero() )
```

A "factory" for building EncryptedArrays.

6.2.3.81 buildGeneralAutomorphPrecon()

```
std::shared_ptr<GeneralAutomorphPrecon> helib::buildGeneralAutomorphPrecon (
            const Ctxt & ctxt,
            long dim,
            const EncryptedArray & ea )
```

6.2.3.82 buildLinPolyCoeffs() [1/2]

```
void helib::buildLinPolyCoeffs (
            NTL::vec_GF2E & C,
            const NTL::vec_GF2E & L,
            long p,
            long r )
```

A version for GF2: must be called with p == 2 and r == 1.

6.2.3.83 buildLinPolyCoeffs() [2/2]

```
void helib::buildLinPolyCoeffs (
            NTL::vec_zz_pE & C,
            const NTL::vec_zz_pE & L,
            long p,
            long r )
```

Combination of buildLinPolyMatrix and ppsolve.

Obtain the linearized polynomial coefficients from a vector L representing the action of a linear map on the standard basis for zz_pE over zz_p.

NTL's current smallint modulus, zz_p::modulus(), is assumed to be p^r, for p prime, r >= 1 integer.

6.2.3.84 buildLinPolyMatrix() [1/2]

```
void helib::buildLinPolyMatrix (
            NTL::mat_GF2E & M,
            long p )
```

6.2.3.85 buildLinPolyMatrix() [2/2]

```
void helib::buildLinPolyMatrix (
            NTL::mat_zz_pE & M,
            long p )
```

6.2.3.86 buildLookupTable()

```
void helib::buildLookupTable (
            std::vector< zzX > & T,
            std::function< double(double)> f,
            long nbits_in,
            long scale_in,
            long sign_in,
            long nbits_out,
            long scale_out,
            long sign_out,
            const EncryptedArray & ea )
```

Built a table-lookup for a function in fixed-point representation.

@function buildLookupTable FIXED-POINT CONVENTIONS: Fixed-point numbers are specified by a triple (nbits,scale,signed). Such a number is represented as an integer x with nbits bits. If signed == 1, then x is treated as a signed integer in 2's compliment; otherwise it is as an unsigned integer. The value represented by x is x∗2^{scale}.

The buildLookupTable function builds a lookup table T, which can be used in conjunction with the tableLookup function above. The size of T will be 2^{nbits_in}. For every signed integer x with bit-size 'nbits_in', we will have T[x] = f(x ∗ 2^{scale_in}) ∗ 2^{-scale_out}), rounded to the nearest integer and truncated to 'nbits_out' bits. The bits are packed inside the slots, so it is assumed that each slot has enough room to fit these many bits. (Otherwise we only keep as many low-order bits as fit in a slot.)

SATURATED ARITHMETIC: Applications of f that return a result that is too large to represent in the output format will be converted to the maximum representable value. Similarly, Applications of f that return a result that is too small will be converted to the minimal representable value. (This applies also to applications of f that return infinites, NaNs will just be mapped to zero.) For this to work correctly, you should be working with standard IEEE arithmetic...which will be the case on almost all platforms.

EXAMPLE:

buildLookupTable(T, [](double x){ return 1/x;}, nbits_in, scale_in, nbits_out, scale_out, sign_out, ea)

will build a lookup table for inversion.

6.2.3.87 buildModChain()

```
void helib::buildModChain (
            Context & context,
            long nBits,
            long nDgts = 3,
            bool willBeBootstrappable = false,
            long skHwt = 0,
            long resolution = 3,
            long bitsInSpecialPrimes = 0 )
```

6.2.3.88 buildPAlgebraMod()

```
PAlgebraModBase * helib::buildPAlgebraMod (
            const PAlgebra & zMStar,
            long r )
```

Builds a table, of type PA_GF2 if p == 2 and r == 1, and PA_zz_p otherwise.

6.2.3.89 buildRandomBlockMatrix()

```
BlockMatMul1D * helib::buildRandomBlockMatrix (
            const EncryptedArray & ea,
            long dim )
```

6.2.3.90 buildRandomFullBlockMatrix()

```
BlockMatMulFull * helib::buildRandomFullBlockMatrix (
            const EncryptedArray & ea )
```

6.2.3.91 buildRandomFullMatrix()

```
MatMulFull * helib::buildRandomFullMatrix (
            const EncryptedArray & ea )
```

6.2.3.92 buildRandomMatrix()

```
MatMul1D * helib::buildRandomMatrix (
            const EncryptedArray & ea,
            long dim )
```

6.2.3.93 buildRandomMultiBlockMatrix()

```
BlockMatMul1D * helib::buildRandomMultiBlockMatrix (
            const EncryptedArray & ea,
            long dim )
```

6.2.3.94 buildRandomMultiMatrix()

```
MatMul1D * helib::buildRandomMultiMatrix (
            const EncryptedArray & ea,
            long dim )
```

6.2.3.95 buildUnpackSlotEncoding()

```
void helib::buildUnpackSlotEncoding (
            std::vector< zzX > & unpackSlotEncoding,
            const EncryptedArray & ea )
```

6.2.3.96 calcPolyNormBnd()

```
double helib::calcPolyNormBnd (
            long m )
```

6.2.3.97 card()

```
long helib::card (
            const IndexSet & s )
```

Functional cardinality.

6.2.3.98 CheckCtxt()

```
void helib::CheckCtxt (
            const Ctxt & c,
            const char * label )
```

print to cerr some info about ciphertext

6.2.3.99 checkNoise()

```
void helib::checkNoise (
            const Ctxt & ctxt,
            const SecKey & sk,
            const std::string & msg,
            double thresh = 10.0 )
```

6.2.3.100 CKKS_canonicalEmbedding() [1/3]

```
void helib::CKKS_canonicalEmbedding (
            std::vector< cx_double > & v,
            const NTL::ZZX & f,
            const PAlgebra & palg )
```

6.2.3.101 CKKS_canonicalEmbedding() [2/3]

```
void helib::CKKS_canonicalEmbedding (
            std::vector< cx_double > & v,
            const std::vector< double > & f,
            const PAlgebra & palg )
```

6.2.3.102 CKKS_canonicalEmbedding() [3/3]

```
void helib::CKKS_canonicalEmbedding (
            std::vector< cx_double > & v,
            const zzX & f,
            const PAlgebra & palg )
```

Computes canonical embedding. Requires p==-1 and m==2^k where k >=2 and f.length() < m/2. Sets v[m/4-1-i] = DFT[palg.ith_rep(i)] for i in range(m/4), where DFT[j] = f(W^j) for j in range(m), and W = exp(-2*pi*I/m).

6.2.3.103 CKKS_embedInSlots()

```
void helib::CKKS_embedInSlots (
            zzX & f,
            const std::vector< cx_double > & v,
            const PAlgebra & palg,
            double scaling )
```

Requires p==-1 and m==2^k where k >=2. Computes the inverse of canonical embedding, scaled by scaling and then rounded to nearest integer.

6.2.3.104 cleanupDebugGlobals()

```
void helib::cleanupDebugGlobals ( ) [inline]
```

Cleanup function for clearing the global debug variables.

6.2.3.105 clear()

```
void helib::clear (
            zzX & a ) [inline]
```

6.2.3.106 closeToOne()

```
bool helib::closeToOne (
            const NTL::xdouble & x,
            long p ) [inline]
```

6.2.3.107 coeffsL2Norm() [1/3]

```
NTL::xdouble helib::coeffsL2Norm (
            const DoubleCRT & f )  [inline]
```

6.2.3.108 coeffsL2Norm() [2/3]

```
NTL::xdouble helib::coeffsL2Norm (
            const NTL::ZZX & f )  [inline]
```

6.2.3.109 coeffsL2Norm() [3/3]

```
double helib::coeffsL2Norm (
            const zzX & f )  [inline]
```

6.2.3.110 coeffsL2NormSquared() [1/3]

```
NTL::xdouble helib::coeffsL2NormSquared (
            const DoubleCRT & f )
```

6.2.3.111 coeffsL2NormSquared() [2/3]

```
NTL::xdouble helib::coeffsL2NormSquared (
            const NTL::ZZX & f )
```

6.2.3.112 coeffsL2NormSquared() [3/3]

```
double helib::coeffsL2NormSquared (
            const zzX & f )
```

The L2-norm of an element (in coefficient representation)

6.2.3.113 comparePAlgebra() [1/2]

```
bool helib::comparePAlgebra (
            const PAlgebra & palg,
            unsigned long m,
            unsigned long p,
            unsigned long r,
            const std::vector< long > & gens,
            const std::vector< long > & ords )
```

returns true if the palg parameters match the rest, false otherwise

6.2.3.114 comparePAlgebra() [2/2]

```
bool helib::comparePAlgebra (
            const PAlgebra & palg,
            unsigned long m,
            unsigned long p,
            UNUSED unsigned long r,
            const std::vector< long > & gens,
            const std::vector< long > & ords )
```

6.2.3.115 compareTwoNumbers() [1/2]

```
void helib::compareTwoNumbers (
            CtPtrs & max,
            CtPtrs & min,
            Ctxt & mu,
            Ctxt & ni,
            const CtPtrs & a,
            const CtPtrs & b,
            bool twosComplement = false,
            std::vector< zzX > * unpackSlotEncoding = nullptr )
```

Compares two integers in binary `a`, `b`. Returns `max(a, b)`, `min(a, b)` and indicator bits `mu=(a>b)` and `ni=(a<b)`

Parameters

max	Maximum of `a` and `b`.
min	Minimum of `a` and `b`.
mu	Indicator bits `mu=(a>b)`.
ni	Indicator bits `ni=(a<b)`.

Parameters

a	First number to compare.
b	Second number to compare.
twosComplement	When set to `true`, the inputs are signed integers in 2's complement. If set to `false` (default), unsigned comparison is performed.
unpackSlotEncoding	Vector of constants for unpacking, as used in bootstrapping.

Note

If `a=b` then `mu=ni=0`

6.2.3.116 compareTwoNumbers() [2/2]

```
void helib::compareTwoNumbers (
            Ctxt & mu,
            Ctxt & ni,
            const CtPtrs & a,
            const CtPtrs & b,
            bool twosComplement = false,
            std::vector< zzX > * unpackSlotEncoding = nullptr )
```

Compares two integers in binary `a`, `b`. Returns only indicator bits `mu`=(`a`>`b`) and `ni`=(`a`<`b`).

Parameters

mu	Indicator bits `mu`=(`a`>`b`).
ni	Indicator bits `ni`=(`a`<`b`).
a	First number to compare.
b	Second number to compare.
twosComplement	When set to `true`, the inputs are signed integers in 2's complement. If set to `false` (default), unsigned comparison is performed.

Parameters

unpackSlotEncoding	Vector of constants for unpacking, as used in bootstrapping.

Note

If a=b then mu=ni=0

6.2.3.117 compareTwoNumbersImplementation()

```
void helib::compareTwoNumbersImplementation (
            CtPtrs & max,
            CtPtrs & min,
            Ctxt & mu,
            Ctxt & ni,
            const CtPtrs & aa,
            const CtPtrs & bb,
            bool twosComplement,
            std::vector< zzX > * unpackSlotEncoding,
            bool cmp_only )
```

6.2.3.118 computeAllProducts()

```
void helib::computeAllProducts (
            CtPtrs & products,
            const CtPtrs & array,
            std::vector< zzX > * unpackSlotEncoding = nullptr )
```

For an n-size array, compute the 2^n products products[j] = \prod_{i s.t. j_i=1} array[i] \times \prod_{i s.t. j_i=0}(a-array[i])

6.2.3.119 computeDivVec()

```
void helib::computeDivVec (
            NTL::Vec< long > & divVec,
            long m,
            const NTL::Vec< long > & powVec )   [inline]
```

6.2.3.120 computeIntervalForMul()

```
void helib::computeIntervalForMul (
            double & lo,
            double & hi,
            const Ctxt & ctxt1,
            const Ctxt & ctxt2 )
```

6.2.3.121 computeIntervalForSqr()

```
void helib::computeIntervalForSqr (
            double & lo,
            double & hi,
            const Ctxt & ctxt )
```

6.2.3.122 computeInvVec()

```
void helib::computeInvVec (
            NTL::Vec< long > & invVec,
            const NTL::Vec< long > & divVec,
            const NTL::Vec< long > & powVec )  [inline]
```

6.2.3.123 ComputeOneGenMapping()

```
void helib::ComputeOneGenMapping (
            Permut & genMap,
            const OneGeneratorTree & T )
```

to a single generator tree

6.2.3.124 computeProd() [1/2]

```
long helib::computeProd (
            const NTL::Vec< long > & vec )
```

returns \prod_d vec[d]

6.2.3.125 computeProd() [2/2]

```
long helib::computeProd (
            const std::vector< long > & vec )
```

6.2.3.126 concatBinaryNums()

```
void helib::concatBinaryNums (
            CtPtrs & output,
            const CtPtrs & a,
            const CtPtrs & b )
```

Concatenates two binary numbers into a single `CtPtrs` object. E.g. If `a=10111`, `b=00101` then `output = 1011100101`.

Concatenate two binary numbers into a single `CtPtrs` object.

Parameters

output	Equal to the concatenation of `a` and `b`.
a	First number to copy into `output`.
b	Second number to concatenate to `a`.

Note

The size of `output` must be of size `a.size() + b.size()`.

6.2.3.127 conv() [1/2]

```
void helib::conv (
            DoubleCRT & d,
            const NTL::ZZX & p ) [inline]
```

6.2.3.128 conv() [2/2]

```
void helib::conv (
            NTL::ZZX & p,
            const DoubleCRT & d )  [inline]
```

6.2.3.129 convert() [1/18]

```
template<typename T1 , typename T2 >
T1 helib::convert (
            const T2 & v2 )
```

6.2.3.130 convert() [2/18]

```
void helib::convert (
            long & x1,
            const NTL::GF2X & x2 )  [inline]
```

6.2.3.131 convert() [3/18]

```
void helib::convert (
            long & x1,
            const NTL::zz_pX & x2 )  [inline]
```

6.2.3.132 convert() [4/18]

```
void helib::convert (
            NTL::GF2X & out,
            const NTL::Vec< long > & in )
```

6.2.3.133 convert() [5/18]

```
void helib::convert (
            NTL::mat_zz_pE & X,
            const std::vector< std::vector< NTL::ZZX >> & A )
```

6.2.3.134 convert() [6/18]

```
void helib::convert (
            NTL::Vec< long > & out,
            const NTL::GF2X & in )
```

6.2.3.135 convert() [7/18]

```
void helib::convert (
            NTL::Vec< long > & out,
            const NTL::zz_pX & in,
            bool symmetric = true )
```

6.2.3.136 convert() [8/18]

```
void helib::convert (
            NTL::Vec< long > & out,
            const NTL::ZZX & in )
```

6.2.3.137 convert() [9/18]

```
template<typename T1 , typename T2 >
void helib::convert (
            NTL::Vec< T1 > & v1,
            const std::vector< T2 > & v2 )
```

6.2.3.138 convert() [10/18]

```
void helib::convert (
            NTL::vec_zz_pE & X,
            const std::vector< NTL::ZZX > & A )
```

6.2.3.139 convert() [11/18]

```
void helib::convert (
            NTL::zz_pX & x,
            const zzX & a )  [inline]
```

6.2.3.140 convert() [12/18]

```
void helib::convert (
            NTL::ZZX & out,
            const NTL::Vec< long > & in )
```

6.2.3.141 convert() [13/18]

```
void helib::convert (
            std::vector< NTL::ZZX > & X,
            const NTL::vec_zz_pE & A )
```

6.2.3.142 convert() [14/18]

```
void helib::convert (
            std::vector< std::vector< NTL::ZZX >> & X,
            const NTL::mat_zz_pE & A )
```

6.2.3.143 convert() [15/18]

```
template<typename T >
void helib::convert (
            std::vector< T > & v1,
            const std::vector< T > & v2 )
```

Trivial type conversion, useful for generic code.

6.2.3.144 convert() [16/18]

```
template<typename T1 , typename T2 >
void helib::convert (
            std::vector< T1 > & v1,
            const NTL::Vec< T2 > & v2 )
```

6.2.3.145 convert() [17/18]

```
template<typename T1 , typename T2 >
void helib::convert (
            std::vector< T1 > & v1,
            const std::vector< T2 > & v2 )
```

generic vector conversion routines

6.2.3.146 convert() [18/18]

```
template<typename T1 , typename T2 >
void helib::convert (
            T1 & x1,
            const T2 & x2 )
```

A generic template that resolves to NTL's conv routine.

6.2.3.147 convertDataToSlotVector()

```
template<typename From , typename Scheme >
std::vector<typename Scheme::SlotType> helib::convertDataToSlotVector (
            const std::vector< From > & data,
            const Context & context ) [inline]
```

Converts `std::vector<From>` to `std::vector<Scheme::SlotType>`.

Template Parameters

From	Type of the element in the input vector.
Scheme	The encryption scheme to be used, must be `BGV` or `CKKS`.

Parameters

data	Vector to be converted.

Returns

Vector of converted values of type `Scheme::SlotType`.

Note

Only exists for `BGV` and `CKKS`.

6.2.3.148 CRTcoeff()

```
long helib::CRTcoeff (
            long p,
            long q,
            bool symmetric = false ) [inline]
```

Returns a CRT coefficient: x = (0 mod p, 1 mod q). If symmetric is set then x \in [-pq/2, pq/2), else x \in [0,pq)

6.2.3.149 ctxtPrimeSize()

```
long helib::ctxtPrimeSize (
            long nBits )
```

6.2.3.150 Cyclotomic()

```
NTL::ZZX helib::Cyclotomic (
            long N )
```

Compute cyclotomic polynomial.

6.2.3.151 decode() [1/2]

```
void helib::decode (
            const EncryptedArray & ea,
            std::vector< long > & array,
            const PlaintextArray & pa )
```

6.2.3.152 decode() [2/2]

```
void helib::decode (
            const EncryptedArray & ea,
            std::vector< NTL::ZZX > & array,
            const PlaintextArray & pa )
```

6.2.3.153 decryptAndCompare()

```
bool helib::decryptAndCompare (
            const Ctxt & ctxt,
            const SecKey & sk,
            const EncryptedArray & ea,
            const PlaintextArray & pa )
```

6.2.3.154 decryptAndPrint()

```
void helib::decryptAndPrint (
            std::ostream & s,
            const Ctxt & ctxt,
            const SecKey & sk,
            const EncryptedArray & ea,
            long flags = 0 )
```

6.2.3.155 decryptBinaryNums()

```
void helib::decryptBinaryNums (
            std::vector< long > & pNums,
            const CtPtrs & eNums,
            const SecKey & sKey,
            const EncryptedArray & ea,
            bool twosComplement = false,
            bool allSlots = true )
```

Decrypt the binary numbers that are encrypted in eNums.

Parameters

pNums	vector to decrypt the binary numbers into.
eNums	encrypted binary numbers of which to be decrypted.
sKey	secret key used for decryption.
ea	encrypted array that holds necessary information for decryption.

Parameters

twosComplement	when set to true, the number to decrypt is a signed integer in 2's complement.
allSlots	when set to false, return only the subcube with index=0 in the last dimension within each ciphertext.

The bits are encrypted in a bit-sliced manner. Namely, encNums[0] contains the LSB of all the numbers, encNums[1] the next bits from all, etc. If twosComplement==true then the number is interpreted as a signed integer in 2's-complement representation. If allSlots==false then we only return the subcube with index i=0 in the last dimension within each ciphertext. Namely, the bit for the j'th counter is found in slot of index j∗sizeOf(lastDim).

6.2.3.156 defaultPmiddle()

```
long helib::defaultPmiddle (
            long delta )  [inline]
```

6.2.3.157 defaultQmiddle()

```
long helib::defaultQmiddle (
            long delta )  [inline]
```

6.2.3.158 DestMulAdd()

```
void helib::DestMulAdd (
            Ctxt & x,
            const std::shared_ptr< ConstMultiplier > & a,
            Ctxt & b )
```

6.2.3.159 disjoint()

```
bool helib::disjoint (
            const IndexSet & s1,
            const IndexSet & s2 ) [inline]
```

Functional disjoint.

6.2.3.160 div() [1/2]

```
void helib::div (
            std::vector< NTL::ZZX > & x,
            const std::vector< NTL::ZZX > & a,
            long b )
```

6.2.3.161 div() [2/2]

```
void helib::div (
            zzX & res,
            const zzX & a,
            long b )
```

6.2.3.162 divc()

```
long helib::divc (
            long a,
            long b ) [inline]
```

returns ceiling(a/b); assumes a >=0, b>0, a+b <= MAX_LONG

6.2.3.163 DoubleCRT::Op< DoubleCRT::AddFun >() [1/3]

```
template DoubleCRT& helib::DoubleCRT::Op< DoubleCRT::AddFun > (
            const DoubleCRT & other,
            AddFun fun,
            bool matchIndexSets )
```

6.2.3.164 DoubleCRT::Op< DoubleCRT::AddFun >() [2/3]

```
template DoubleCRT& helib::DoubleCRT::Op< DoubleCRT::AddFun > (
            const NTL::ZZ & num,
            AddFun fun )
```

6.2.3.165 DoubleCRT::Op< DoubleCRT::AddFun >() [3/3]

```
template DoubleCRT& helib::DoubleCRT::Op< DoubleCRT::AddFun > (
            const NTL::ZZX & poly,
            AddFun fun )
```

6.2.3.166 DoubleCRT::Op< DoubleCRT::MulFun >() [1/2]

```
template DoubleCRT& helib::DoubleCRT::Op< DoubleCRT::MulFun > (
            const NTL::ZZ & num,
            MulFun fun )
```

6.2.3.167 DoubleCRT::Op< DoubleCRT::MulFun >() [2/2]

```
template DoubleCRT& helib::DoubleCRT::Op< DoubleCRT::MulFun > (
            const NTL::ZZX & poly,
            MulFun fun )
```

6.2.3.168 DoubleCRT::Op< DoubleCRT::SubFun >() [1/3]

```
template DoubleCRT& helib::DoubleCRT::Op< DoubleCRT::SubFun > (
            const DoubleCRT & other,
            SubFun fun,
            bool matchIndexSets )
```

6.2.3.169 DoubleCRT::Op< DoubleCRT::SubFun >() [2/3]

```
template DoubleCRT& helib::DoubleCRT::Op< DoubleCRT::SubFun > (
            const NTL::ZZ & num,
            SubFun fun )
```

6.2.3.170 DoubleCRT::Op< DoubleCRT::SubFun >() [3/3]

```
template DoubleCRT& helib::DoubleCRT::Op< DoubleCRT::SubFun > (
            const NTL::ZZX & poly,
            SubFun fun )
```

6.2.3.171 EDF()

```
void helib::EDF (
            NTL::vec_zz_pX & v,
            const NTL::zz_pX & f,
            long d )
```

6.2.3.172 embeddingLargestCoeff() [1/4]

```
NTL::xdouble helib::embeddingLargestCoeff (
            const Ctxt & ctxt,
            const SecKey & sk )
```

6.2.3.173 embeddingLargestCoeff() [2/4]

```
NTL::xdouble helib::embeddingLargestCoeff (
            const NTL::ZZX & f,
            const PAlgebra & palg )
```

6.2.3.174 embeddingLargestCoeff() [3/4]

```
double helib::embeddingLargestCoeff (
            const std::vector< double > & f,
            const PAlgebra & palg )
```

6.2.3.175 embeddingLargestCoeff() [4/4]

```
double helib::embeddingLargestCoeff (
            const zzX & f,
            const PAlgebra & palg )
```

Computing the L-infinity norm of the canonical embedding Assumed: deg(f) < phi(m).

6.2.3.176 embeddingLargestCoeff_x2()

```
void helib::embeddingLargestCoeff_x2 (
            double & norm1,
            double & norm2,
            const std::vector< double > & f1,
            const std::vector< double > & f2,
            const PAlgebra & palg )
```

6.2.3.177 empty()

```
bool helib::empty (
            const IndexSet & s )  [inline]
```

6.2.3.178 encode() [1/4]

```
void helib::encode (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            const NTL::ZZX & val )
```

6.2.3.179 encode() [2/4]

```
void helib::encode (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            const std::vector< long > & array )
```

6.2.3.180 encode() [3/4]

```
void helib::encode (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            const std::vector< NTL::ZZX > & array )
```

6.2.3.181 encode() [4/4]

```
void helib::encode (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            long val )
```

6.2.3.182 endBuildModChain()

```
void helib::endBuildModChain (
            Context & context )
```

6.2.3.183 equals() [1/3]

```
bool helib::equals (
            const EncryptedArray & ea,
            const PlaintextArray & pa,
            const PlaintextArray & other )
```

6.2.3.184 equals() [2/3]

```
bool helib::equals (
            const EncryptedArray & ea,
            const PlaintextArray & pa,
            const std::vector< long > & other )
```

6.2.3.185 equals() [3/3]

```
bool helib::equals (
            const EncryptedArray & ea,
            const PlaintextArray & pa,
            const std::vector< NTL::ZZX > & other )
```

6.2.3.186 extendExtractDigits()

```
void helib::extendExtractDigits (
            std::vector< Ctxt > & digits,
            const Ctxt & c,
            long r,
            long e )
```

6.2.3.187 extractDigits() [1/2]

```
void helib::extractDigits (
            std::vector< Ctxt > & digits,
            const Ctxt & c,
            long r,
            bool shortCut )  [inline]
```

6.2.3.188 extractDigits() [2/2]

```
void helib::extractDigits (
            std::vector< Ctxt > & digits,
            const Ctxt & c,
            long r = 0 )
```

Extract the mod-p digits of a mod-p^r ciphertext.

extractDigits returns in the slots of digits[j] the j'th-lowest digits from the integers in the slots of the input. Namely, the i'th slot of digits[j] contains the j'th digit in the p-base expansion of the integer in the i'th slot of the *this.

If r==0 then it is set to c.effectiveR(). It is assumed that the slots of *this contains integers mod p^r, i.e., that only the free terms are nonzero. If that assumptions does not hold then the result will not be a valid ciphertext anymore.

The "shortcut" flag is deprecated, it often leads to catastrophic failure in the noise estimate. Calling the function with shortcut=true has not effect, except printing a warning message to cerr.

The output ciphertext digits[j] contains the j'th digit in the base-p expansion of the input, and its plaintext space is modulo p^{r-j}. All the ciphertexts in the output are at the same level.

6.2.3.189 extractDigitsPacked()

```
void helib::extractDigitsPacked (
            Ctxt & ctxt,
            long botHigh,
            long r,
            long ePrime,
            const std::vector< NTL::ZZX > & unpackSlotEncoding )
```

6.2.3.190 extractDigitsThin()

```
void helib::extractDigitsThin (
            Ctxt & ctxt,
            long botHigh,
            long r,
            long ePrime )
```

6.2.3.191 factorize() [1/3]

```
void helib::factorize (
            NTL::Vec< NTL::Pair< long, long >> & factors,
            long N )
```

Factoring by trial division, only works for N<2^{60} primes and multiplicities are recorded.

6.2.3.192 factorize() [2/3]

```
void helib::factorize (
            std::vector< long > & factors,
            long N )
```

Factoring by trial division, only works for N<2^{60}, only the primes are recorded, not their multiplicity.

6.2.3.193 factorize() [3/3]

```
void helib::factorize (
            std::vector< NTL::ZZ > & factors,
            const NTL::ZZ & N )
```

6.2.3.194 fastPower()

```
void helib::fastPower (
            Ctxt & ctxt,
            long d )
```

6.2.3.195 fetch_saved_values()

```
const std::vector< double > * helib::fetch_saved_values (
            const char * name )
```

6.2.3.196 fifteenOrLess4Four()

```
long helib::fifteenOrLess4Four (
            const CtPtrs & out,
            const CtPtrs & in,
            long sizeLimit = 4 )
```

Add together up to fifteen {0,1} integers, producing a 4-bit counter.

Parameters

out	4-bit counter to be outputted.
in	bits to be counted.
sizeLimit	number of bits to compute on, taken from the least significant end.

Returns

number of output bits that are not identically zero (i.e. != null).

Adding fifteen input bits, getting a 4-bit counter. Some of the input pointers may be null, but output pointers must point to allocated Ctxt objects. If sizeLimit<4, only that many bits are computed (taken from the least significant end).

6.2.3.197 findGenerators()

```
long helib::findGenerators (
            std::vector< long > & gens,
            std::vector< long > & ords,
            long m,
            long p,
            const std::vector< long > & candidates = std::vector<long>() )
```

Returns in gens a generating set for Zm∗ /

, and in ords the order of these generators. Return value is the order of p in Zm∗.

6.2.3.198 FindM()

```
long helib::FindM (
            long k,
            long nBits,
            long c,
            long p,
            long d,
            long s,
            long chosen_m,
            bool verbose = false )
```

Returns smallest parameter m satisfying various constraints:

Parameters

k	security parameter
L	number of levels
c	number of columns in key switching matrices
p	characteristic of plaintext space
d	embedding degree (d ==0 or d==1 => no constraint)
s	at least that many plaintext slots

Parameters

chosen_m	preselected value of m (0 => not preselected) Fails with an error message if no suitable m is found prints an informative message if verbose == true

6.2.3.199 findMinBitCapacity() [1/3]

```
long helib::findMinBitCapacity (
            const CtPtrMat & m )  [inline]
```

6.2.3.200 findMinBitCapacity() [2/3]

```
long helib::findMinBitCapacity (
            const CtPtrs & v )  [inline]
```

6.2.3.201 findMinBitCapacity() [3/3]

```
long helib::findMinBitCapacity (
            std::initializer_list< const CtPtrs * > list )  [inline]
```

6.2.3.202 FindPrimitiveRoot() [1/2]

```
void helib::FindPrimitiveRoot (
            NTL::zz_p & r,
            unsigned long e )
```

Find e-th root of unity modulo the current modulus.

6.2.3.203 FindPrimitiveRoot() [2/2]

```
void helib::FindPrimitiveRoot (
            NTL::ZZ_p & r,
            unsigned long e )
```

6.2.3.204 FindPrimRootT()

```
template<typename zp , typename zz >
void helib::FindPrimRootT (
            zp & root,
            unsigned long e )
```

6.2.3.205 frobeniusAutomorph() [1/2]

```
void helib::frobeniusAutomorph (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            const NTL::Vec< long > & vec )
```

6.2.3.206 frobeniusAutomorph() [2/2]

```
void helib::frobeniusAutomorph (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            long j )
```

6.2.3.207 FrobeniusMap()

```
NTL::zz_pEX helib::FrobeniusMap (
            const NTL::zz_pEXModulus & F )
```

6.2.3.208 fsquare()

```
double helib::fsquare (
            double x )  [inline]
```

Return the square of a number as a double.

6.2.3.209 GenBabySteps()

```
void helib::GenBabySteps (
            std::vector< std::shared_ptr< Ctxt >> & v,
            const Ctxt & ctxt,
            long dim,
            bool clean )
```

6.2.3.210 getG()

```
NTL::ZZX helib::getG (
            const EncryptedArray & ea )
```

6.2.3.211 getHyperColumn() [1/3]

```
template void helib::getHyperColumn (
            NTL::Vec< long > & v,
            const ConstCubeSlice< long > & s,
            long pos )
```

6.2.3.212 getHyperColumn() [2/3]

```
template void helib::getHyperColumn (
            NTL::Vec< NTL::zz_p > & v,
            const ConstCubeSlice< NTL::zz_p > & s,
            long pos )
```

6.2.3.213 getHyperColumn() [3/3]

```
template<typename T >
void helib::getHyperColumn (
            NTL::Vec< T > & v,
            const ConstCubeSlice< T > & s,
            long pos )
```

getHyperColumn reads out a (multi-dimensional) column from a slice. The parameter pos specifies the position of the column, which must be in the range 0 <= pos < s.getProd(1). The vector v is filled with values whose coordinate in the lower dimensional subcube is equal to pos. The length of v will be set to s.getDim(0).

6.2.3.214 getPhimXMod()

```
const NTL::zz_pXModulus & helib::getPhimXMod (
            const PAlgebra & palg )
```

6.2.3.215 getTimerByName()

```
const FHEtimer * helib::getTimerByName (
            const char * name )
```

6.2.3.216 GetTimerClock()

```
unsigned long helib::GetTimerClock ( )
```

6.2.3.217 incrementalProduct()

```
void helib::incrementalProduct (
            std::vector< Ctxt > & v )
```

For i=n-1...0, set v[i]=prod_{j<=i} v[j] This implementation uses depth log n and (nlog n)/2 products

6.2.3.218 incrementalZeroTest()

```
void helib::incrementalZeroTest (
            Ctxt * res[ ],
            const EncryptedArray & ea,
            const Ctxt & ctxt,
            long n )
```

6.2.3.219 innerProduct() [1/9]

```
Ctxt helib::innerProduct (
            const CtPtrs & v1,
            const CtPtrs & v2 ) [inline]
```

6.2.3.220 innerProduct() [2/9]

```
Ctxt helib::innerProduct (
            const std::vector< Ctxt > & v1,
            const std::vector< Ctxt > & v2 ) [inline]
```

6.2.3.221 innerProduct() [3/9]

```
Ctxt helib::innerProduct (
            const std::vector< Ctxt > & v1,
            const std::vector< DoubleCRT > & v2 ) [inline]
```

6.2.3.222 innerProduct() [4/9]

```
Ctxt helib::innerProduct (
            const std::vector< Ctxt > & v1,
            const std::vector< NTL::ZZX > & v2 ) [inline]
```

6.2.3.223 innerProduct() [5/9]

```
void helib::innerProduct (
            Ctxt & result,
            const CtPtrs & v1,
            const CtPtrs & v2 )
```

6.2.3.224 innerProduct() [6/9]

```
void helib::innerProduct (
            Ctxt & result,
            const std::vector< Ctxt > & v1,
            const std::vector< Ctxt > & v2 )
```

6.2.3.225 innerProduct() [7/9]

```
void helib::innerProduct (
            Ctxt & result,
            const std::vector< Ctxt > & v1,
            const std::vector< DoubleCRT > & v2 )
```

Compute the inner product of a vectors of ciphertexts and a constant vector.

6.2.3.226 innerProduct() [8/9]

```
void helib::innerProduct (
            Ctxt & result,
            const std::vector< Ctxt > & v1,
            const std::vector< NTL::ZZX > & v2 )
```

6.2.3.227 innerProduct() [9/9]

```
template<typename Scheme >
void helib::innerProduct (
            Ptxt< Scheme > & result,
            const std::vector< Ptxt< Scheme >> & first_vec,
            const std::vector< Ptxt< Scheme >> & second_vec )
```

Free function that computes the inner product of two vectors of `Ptxt`.

Parameters

result	The output `Ptxt` that will hold the result.
first_vec	The first input vector of plaintexts.
second_vec	The second input vector of plaintexts.

Note

If the two vector sizes differ, the shorter vector will be padded with zeroes.

6.2.3.228 interpolateMod()

```
void helib::interpolateMod (
            NTL::ZZX & poly,
            const NTL::vec_long & x,
            const NTL::vec_long & y,
            long p,
            long e = 1 )
```

Interpolate polynomial such that poly(x[i] mod p)=y[i] (mod p^e) It is assumed that the points x[i] are all distinct modulo p.

6.2.3.229 intVecCRT() [1/4]

```
template bool helib::intVecCRT (
            NTL::vec_ZZ & ,
            const NTL::ZZ & ,
            const NTL::Vec< NTL::zz_p > & ,
            long )
```

6.2.3.230 intVecCRT() [2/4]

```
template bool helib::intVecCRT (
            NTL::vec_ZZ & ,
            const NTL::ZZ & ,
            const NTL::vec_long & ,
            long )
```

6.2.3.231 intVecCRT() [3/4]

```
template bool helib::intVecCRT (
            NTL::vec_ZZ & ,
            const NTL::ZZ & ,
            const NTL::vec_ZZ & ,
            long )
```

6.2.3.232 intVecCRT() [4/4]

```
template<class zzvec >
bool helib::intVecCRT (
            NTL::vec_ZZ & vp,
            const NTL::ZZ & p,
            const zzvec & vq,
            long q )
```

Incremental integer CRT for vectors.

Expects co-primes p,q with q odd, and such that all the entries in v1 are in [-p/2,p/2). Returns in v1 the CRT of vp mod p and vq mod q, as integers in [-pq/2, pq/2). Uses the formula:

$$CRT(vp, p, vq, q) = vp + [(vq - vp) * p^{-1}]_q * p,$$

where [...]_q means reduction to the interval [-q/2,q/2). Notice that if q is odd then this is the same as reducing to [-(q-1)/2,(q-1)/2], which means that [...]_q $*$ p is in [-p(q-1)/2, p(q-1)/2], and since vp is in [-p/2,p/2) then the sum is indeed in [-pq/2,pq/2).

Return true is both vectors are of the same length, false otherwise

6.2.3.233 InvModpr()

```
void helib::InvModpr (
            NTL::zz_pX & S,
            const NTL::zz_pX & F,
            const NTL::zz_pX & G,
            long p,
            long r )
```

6.2.3.234 is2power()

```
bool helib::is2power (
            long m ) [inline]
```

6.2.3.235 is_in()

```
long helib::is_in (
            long x,
            int * X,
            long sz )
```

Finds whether x is an element of the set X of size sz, Returns -1 it not and the location if true.

6.2.3.236 isDryRun()

```
bool helib::isDryRun ( ) [inline]
```

6.2.3.237 isSetAutomorphVals()

```
bool helib::isSetAutomorphVals ( ) [inline]
```

6.2.3.238 isSetAutomorphVals2()

```
bool helib::isSetAutomorphVals2 ( ) [inline]
```

6.2.3.239 IsZero()

```
bool helib::IsZero (
            const zzX & a ) [inline]
```

6.2.3.240 killVec() [1/2]

```
template<typename T >
void helib::killVec (
            NTL::Vec< T > & vec )
```

6.2.3.241 killVec() [2/2]

```
template<typename T >
void helib::killVec (
            std::vector< T > & vec )
```

NTL/std compatibility.

6.2.3.242 KSGiantStepSize()

```
long helib::KSGiantStepSize (
            long D )
```

Function that returns number of baby steps. Used to keep this and matmul routines "in sync".

6.2.3.243 largestCoeff() [1/5]

```
NTL::ZZ helib::largestCoeff (
            const DoubleCRT & f )
```

6.2.3.244 largestCoeff() [2/5]

```
NTL::ZZ helib::largestCoeff (
            const NTL::Vec< NTL::ZZ > & f )
```

6.2.3.245 largestCoeff() [3/5]

```
template<typename T >
double helib::largestCoeff (
            const NTL::Vec< T > & f )
```

The L-infinity norm of an element (in coefficient representation)

6.2.3.246 largestCoeff() [4/5]

```
NTL::ZZ helib::largestCoeff (
            const NTL::ZZX & f )
```

6.2.3.247 largestCoeff() [5/5]

```
template<typename T >
double helib::largestCoeff (
            const std::vector< T > & f )
```

6.2.3.248 leftBitwiseShift()

```
void helib::leftBitwiseShift (
            CtPtrs & output,
            const CtPtrs & input,
            const long shamt )
```

Left shift `input` by `shamt`.

Shift binary numbers to the left by `shamt`

Parameters

output	Shifted result.
input	The number to be shifted.
shamt	The number to bits to shift by.

Note

This is a left shift only, i.e. the bits are moved to the most-significant end.

`shamt` must be positive.

The size of `output` and `input` must be the same.

6.2.3.249 length()

```
long helib::length (
            GenNodePtr ptr )
```

6.2.3.250 less_than() [1/8]

```
bool helib::less_than (
            const NTL::GF2E & a,
            const NTL::GF2E & b )
```

6.2.3.251 less_than() [2/8]

```
bool helib::less_than (
            const NTL::GF2EX & a,
            const NTL::GF2EX & b )
```

6.2.3.252 less_than() [3/8]

```
bool helib::less_than (
            const NTL::GF2X & a,
            const NTL::GF2X & b )
```

6.2.3.253 less_than() [4/8]

```
bool helib::less_than (
            const NTL::zz_pE & a,
            const NTL::zz_pE & b )
```

6.2.3.254 less_than() [5/8]

```
bool helib::less_than (
            const NTL::zz_pEX & a,
            const NTL::zz_pEX & b )
```

6.2.3.255 less_than() [6/8]

```
bool helib::less_than (
            const NTL::zz_pX & a,
            const NTL::zz_pX & b )
```

6.2.3.256 less_than() [7/8]

```
bool helib::less_than (
            NTL::GF2 a,
            NTL::GF2 b )
```

6.2.3.257 less_than() [8/8]

```
bool helib::less_than (
            NTL::zz_p a,
            NTL::zz_p b )
```

6.2.3.258 log2()

```
double helib::log2 (
            const NTL::xdouble & x )  [inline]
```

Base-2 logarithm.

6.2.3.259 log2_realToEstimatedNoise()

```
double helib::log2_realToEstimatedNoise (
            const Ctxt & ctxt,
            const SecKey & sk )
```

6.2.3.260 longToBitVector()

```
std::vector< long > helib::longToBitVector (
            long num,
            long bitSize )
```

Returns a number as a vector of bits with LSB on the left.

Parameters

num	Number to be converted.
bitSize	Number of bits of the input and output.

Returns

Bit vector representation of num.

Note

`bitSize` must be non-negative.

6.2.3.261 lsize() [1/4]

```
template<typename T >
long helib::lsize (
            const NTL::Vec< T > & v )  [inline]
```

6.2.3.262 lsize() [2/4]

```
template<typename T >
long helib::lsize (
            const PtrMatrix< T > & v )
```

6.2.3.263 lsize() [3/4]

```
template<typename T >
long helib::lsize (
            const PtrVector< T > & v )
```

6.2.3.264 lsize() [4/4]

```
template<typename T >
long helib::lsize (
            const std::vector< T > & v )  [inline]
```

Size of STL vector as a long (rather than unsigned long)

6.2.3.265 make_lazy()

```
template<typename T , typename P , typename...  Args>
void helib::make_lazy (
            const NTL::Lazy< T, P > & obj,
            Args &&...  args )
```

This should go in NTL some day... Just call as make_lazy(obj, ...) to initialize a lazy object via a call to a constructor T(...)

6.2.3.266 make_lazy_with_fun()

```
template<typename T , typename P , typename F , typename...  Args>
void helib::make_lazy_with_fun (
            const NTL::Lazy< T, P > & obj,
            F f,
            Args &&...  args )
```

This should go in NTL some day... Just call as make_lazy(obj, f, ...) to initialize a lazy object via a call to f(∗obj, ...)

6.2.3.267 makeIrredPoly()

```
NTL::ZZX helib::makeIrredPoly (
            long p,
            long d )
```

Return a degree-d irreducible polynomial mod p.

6.2.3.268 mapTo01() [1/4]

```
template void helib::mapTo01 (
            const EncryptedArray & ,
            Ptxt< BGV > & ptxt )
```

6.2.3.269 mapTo01() [2/4]

```
template void helib::mapTo01 (
            const EncryptedArray & ,
            Ptxt< CKKS > & ptxt )
```

6.2.3.270 mapTo01() [3/4]

```
template<typename Scheme >
void helib::mapTo01 (
            const EncryptedArray & ,
            Ptxt< Scheme > & ptxt )
```

6.2.3.271 mapTo01() [4/4]

```
void helib::mapTo01 (
            const EncryptedArray & ea,
            Ctxt & ctxt )
```

6.2.3.272 maximum_flow()

```
long helib::maximum_flow (
            FlowGraph & fg,
            long src,
            long sink )
```

Remove from the graph all the flow-zero edges for (long i=0; i<(long)fg.size(); i++) { FNeighborList::iterator it1=fg[i].begin(); do { FNeighborList::iterator it2 = it1; it1++; // increment the iterator before potentially erasing the edge if (it2->second.flow == 0) fg[i].erase(it2); } while (it1 != fg[i].end()); }

Remove from the graph all the flow-zero edges for (long i=0; i<(long)fg.size(); i++) { FNeighborList::iterator it1=fg[i].begin(); do { FNeighborList::iterator it2 = it1; it1++; // increment the iterator before potentially erasing the edge if (it2->second.flow == 0) fg[i].erase(it2); } while (it1 != fg[i].end()); }

6.2.3.273 mcDiv()

```
long helib::mcDiv (
            long a,
            long b )
```

6.2.3.274 mcMod()

```
long helib::mcMod (
            long a,
            long b )
```

Routines for computing mathematically correct mod and div.

mcDiv(a, b) = floor(a / b), mcMod(a, b) = a - b∗mcDiv(a, b); in particular, mcMod(a, b) is 0 or has the same sign as b

6.2.3.275 mobius()

```
long helib::mobius (
            long n )
```

Compute mobius function (naive method as n is small).

6.2.3.276 ModComp()

```
void helib::ModComp (
            NTL::ZZX & res,
            const NTL::ZZX & g,
            const NTL::ZZX & h,
            const NTL::ZZX & f )
```

Modular composition of polynomials: res = g(h) mod f.

6.2.3.277 mul() [1/7]

```
void helib::mul (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            const PlaintextArray & other )
```

6.2.3.278 mul() [2/7]

```
void helib::mul (
            PlaintextArray & pa,
            const BlockMatMul1D & mat )
```

6.2.3.279 mul() [3/7]

```
void helib::mul (
            PlaintextArray & pa,
            const BlockMatMulFull & mat )
```

6.2.3.280 mul() [4/7]

```
void helib::mul (
            PlaintextArray & pa,
            const MatMul1D & mat )
```

6.2.3.281 mul() [5/7]

```
void helib::mul (
            PlaintextArray & pa,
            const MatMulFull & mat )
```

6.2.3.282 mul() [6/7]

```
void helib::mul (
            std::vector< NTL::ZZX > & x,
            const std::vector< NTL::ZZX > & a,
            long b )
```

6.2.3.283 mul() [7/7]

```
void helib::mul (
            zzX & res,
            const zzX & a,
            long b )
```

6.2.3.284 MulAdd()

```
void helib::MulAdd (
            Ctxt & x,
            const std::shared_ptr< ConstMultiplier > & a,
            const Ctxt & b )
```

6.2.3.285 MulMod() [1/6]

```
NTL::ZZX helib::MulMod (
            const NTL::ZZX & f,
            long a,
            long q ) [inline]
```

6.2.3.286 MulMod() [2/6]

```
NTL::ZZX helib::MulMod (
            const NTL::ZZX & f,
            long a,
            long q,
            bool abs ) [inline]
```

6.2.3.287 MulMod() [3/6]

```
zzX helib::MulMod (
            const zzX & a,
            const zzX & b,
            const PAlgebra & palg ) [inline]
```

6.2.3.288 MulMod() [4/6]

```
void helib::MulMod (
            NTL::ZZX & out,
            const NTL::ZZX & f,
            long a,
            long q )  [inline]
```

6.2.3.289 MulMod() [5/6]

```
void helib::MulMod (
            NTL::ZZX & out,
            const NTL::ZZX & f,
            long a,
            long q,
            bool abs )
```

6.2.3.290 MulMod() [6/6]

```
void helib::MulMod (
            zzX & res,
            const zzX & a,
            const zzX & b,
            const PAlgebra & palg )
```

6.2.3.291 multOrd()

```
long helib::multOrd (
            long p,
            long m )
```

Return multiplicative order of p modulo m, or 0 if GCD(p, m) != 1.

6.2.3.292 multTwoNumbers()

```
void helib::multTwoNumbers (
            CtPtrs & product,
            const CtPtrs & lhs,
            const CtPtrs & rhs,
            bool rhsTwosComplement = false,
            long sizeLimit = 0,
            std::vector< zzX > * unpackSlotEncoding = nullptr )
```

Multiply two numbers in binary representation where each ciphertext of the input vector contains a bit.

Parameters

product	result of the multiplication operation.
lhs	left hand side of the multiplication.
rhs	right hand side of the multiplication.
rhsTwosComplement	flag to state the multiplier is potentially negative.
sizeLimit	number of bits to compute on, taken from the least significant end.
unpackSlotEncoding	vector of constants for unpacking, as used in bootstrapping.

6.2.3.293 negate()

```
void helib::negate (
            const EncryptedArray & ea,
            PlaintextArray & pa )
```

6.2.3.294 negateBinary()

```
void helib::negateBinary (
            CtPtrs & negation,
            const CtPtrs & input )
```

Negates a number in binary 2's complement representation.

Parameters

negation	Reference to the negated number that will be populated.
input	Number to be negated.

Note

`input` will be treated as a number in 2's complement.

`input` must not alias negation.

6.2.3.295 normalize()

```
void helib::normalize (
            zzX & f )
```

6.2.3.296 operator"!=()

```
template<typename T >
bool helib::operator!= (
            const IndexMap< T > & map1,
            const IndexMap< T > & map2 )
```

6.2.3.297 operator&()

```
IndexSet helib::operator& (
            const IndexSet & s,
            const IndexSet & t )
```

intersection

6.2.3.298 operator*()

```
zzX helib::operator* (
            const zzX & a,
            long b )  [inline]
```

6.2.3.299 operator*=()

```
zzX& helib::operator*= (
            zzX & a,
            long b )  [inline]
```

6.2.3.300 operator+()

```
zzX helib::operator+ (
            const zzX & a,
            const zzX & b )  [inline]
```

6.2.3.301 operator+=()

```
zzX& helib::operator+= (
            zzX & a,
            const zzX & b )  [inline]
```

6.2.3.302 operator/() [1/2]

```
IndexSet helib::operator/ (
            const IndexSet & s,
            const IndexSet & t )
```

set minus

6.2.3.303 operator/() [2/2]

```
zzX helib::operator/ (
            const zzX & a,
            long b ) [inline]
```

6.2.3.304 operator/=()

```
zzX& helib::operator/= (
            zzX & a,
            long b ) [inline]
```

6.2.3.305 operator<()

```
bool helib::operator< (
            const IndexSet & s1,
            const IndexSet & s2 )
```

Is s1 strict subset of s2.

6.2.3.306 operator<<() [1/23]

```
std::ostream& helib::operator<< (
            std::ostream & os,
            const PolyMod & poly )
```

Parameters

os	Output `std::ostream`.
poly	`PolyMod` object to be written.

Returns

Input `std::ostream` post writing.

Note

p2r and G are not serialised, see note of `operator>>`.

6.2.3.307 operator<<() [2/23]

```
std::ostream& helib::operator<< (
            std::ostream & os,
            const PolyModRing & ring )
```

Parameters

os	Output std::ostream.
ring	PolyModRing object to be written.

Returns

Input `std::ostream` post writing.

6.2.3.308 operator<<() [3/23]

```
std::ostream & helib::operator<< (
            std::ostream & s,
            const ColPerm & p )
```

6.2.3.309 operator<<() [4/23]

```
std::ostream & helib::operator<< (
            std::ostream & s,
            const CtxtPart & p )
```

6.2.3.310 operator<<() [5/23]

```
std::ostream& helib::operator<< (
            std::ostream & s,
            const CubeSignature & sig ) [inline]
```

6.2.3.311 operator<<() [6/23]

```
std::ostream& helib::operator<< (
            std::ostream & s,
            const GeneratorTrees & trees )
```

6.2.3.312 operator<<() [7/23]

```
std::ostream& helib::operator<< (
            std::ostream & s,
            const ModuliSizes & szs )
```

6.2.3.313 operator<<() [8/23]

```
std::ostream & helib::operator<< (
            std::ostream & s,
            const ModuliSizes::Entry & e )
```

6.2.3.314 operator<<() [9/23]

```
std::ostream& helib::operator<< (
            std::ostream & s,
            const PermNetwork & net )
```

6.2.3.315 operator<<() [10/23]

```
std::ostream& helib::operator<< (
            std::ostream & s,
            const PlaintextArray & pa )  [inline]
```

6.2.3.316 operator<<() [11/23]

```
std::ostream& helib::operator<< (
            std::ostream & s,
            const SKHandle & handle )  [inline]
```

6.2.3.317 operator<<() [12/23]

```
std::ostream& helib::operator<< (
            std::ostream & s,
            const SubDimension & sd )
```

6.2.3.318 operator<<() [13/23]

```
std::ostream& helib::operator<< (
            std::ostream & s,
            GenNodePtr p )
```

6.2.3.319 operator<<() [14/23]

```
std::ostream& helib::operator<< (
            std::ostream & s,
            LongNodePtr p )
```

6.2.3.320 operator<<() [15/23]

```
std::ostream& helib::operator<< (
            std::ostream & s,
            SplitNodePtr p )
```

6.2.3.321 operator<<() [16/23]

```
template<typename T >
std::ostream& helib::operator<< (
            std::ostream & s,
            std::vector< T > v )
```

6.2.3.322 operator<<() [17/23]

```
std::ostream& helib::operator<< (
            std::ostream & str,
            const Context & context )
```

6.2.3.323 operator<<() [18/23]

```
std::ostream& helib::operator<< (
            std::ostream & str,
            const Ctxt & ctxt )
```

6.2.3.324 operator<<() [19/23]

```
std::ostream& helib::operator<< (
            std::ostream & str,
            const DoubleCRT & d )
```

6.2.3.325 operator<<() [20/23]

```
std::ostream & helib::operator<< (
            std::ostream & str,
            const IndexSet & set )
```

6.2.3.326 operator<<() [21/23]

```
std::ostream & helib::operator<< (
            std::ostream & str,
            const KeySwitch & matrix )
```

6.2.3.327 operator<<() [22/23]

```
std::ostream& helib::operator<< (
            std::ostream & str,
            const PubKey & pk )
```

6.2.3.328 operator<<() [23/23]

```
std::ostream& helib::operator<< (
            std::ostream & str,
            const SecKey & sk )
```

6.2.3.329 operator<=()

```
bool helib::operator<= (
            const IndexSet & s1,
            const IndexSet & s2 )
```

Is s1 subset or equal to s2.

6.2.3.330 operator==()

```
template<typename T >
bool helib::operator== (
            const IndexMap< T > & map1,
            const IndexMap< T > & map2 )
```

Comparing maps, by comparing all the elements.

6.2.3.331 operator>() [1/2]

```
bool helib::operator> (
            const IndexSet & s1,
            const IndexSet & s2 )
```

Is s2 strict subset of s1.

6.2.3.332 operator>() [2/2]

```
bool helib::operator> (
            const ModuliSizes::Entry & a,
            const ModuliSizes::Entry & b )  [inline]
```

6.2.3.333 operator>=()

```
bool helib::operator>= (
            const IndexSet & s1,
            const IndexSet & s2 )
```

Is s2 subset or equal to s2.

6.2.3.334 operator>>() [1/12]

```
std::istream& helib::operator>> (
            std::istream & is,
            PolyMod & poly )
```

Parameters

is	Input `std::istream`.
poly	Destination `PolyMod` object.

Returns

Input `std::istream` post reading.

Note

`poly` must be constructed with an appropriate p2r and G **BEFORE** calling this function. For example,

```
PolyMod my_poly(p2r, G);
std::cin » my_poly;
```

6.2.3.335 operator>>() [2/12]

```
std::istream & helib::operator>> (
            std::istream & s,
            CtxtPart & p )
```

6.2.3.336 operator>>() [3/12]

```
std::istream& helib::operator>> (
            std::istream & s,
            ModuliSizes & szs )
```

6.2.3.337 operator>>() [4/12]

```
std::istream & helib::operator>> (
            std::istream & s,
            ModuliSizes::Entry & e )
```

6.2.3.338 operator>>() [5/12]

```
template<typename T >
std::istream& helib::operator>> (
            std::istream & s,
            std::vector< T > & v )
```

6.2.3.339 operator>>() [6/12]

```
std::istream& helib::operator>> (
            std::istream & str,
            Context & context )
```

6.2.3.340 operator>>() [7/12]

```
std::istream& helib::operator>> (
            std::istream & str,
            Ctxt & ctxt )
```

6.2.3.341 operator>>() [8/12]

```
std::istream& helib::operator>> (
            std::istream & str,
            DoubleCRT & d )
```

6.2.3.342 operator>>() [9/12]

```
std::istream & helib::operator>> (
            std::istream & str,
            IndexSet & set )
```

6.2.3.343 operator>>() [10/12]

```
std::istream& helib::operator>> (
            std::istream & str,
            PubKey & pk )
```

6.2.3.344 operator>>() [11/12]

```
std::istream& helib::operator>> (
            std::istream & str,
            SecKey & sk )
```

6.2.3.345 operator>>() [12/12]

```
std::istream& helib::operator>> (
            std::istream & str,
            SKHandle & handle )
```

6.2.3.346 operator^()

```
IndexSet helib::operator^ (
            const IndexSet & s,
            const IndexSet & t )
```

exclusive-or

6.2.3.347 operator"|()

```
IndexSet helib::operator| (
            const IndexSet & s,
            const IndexSet & t )
```

union

6.2.3.348 optimalBenes()

```
void helib::optimalBenes (
            long n,
            long budget,
            bool good,
            long & cost,
            LongNodePtr & solution )
```

6.2.3.349 optimalBenesAux()

```
BenesMemoEntry helib::optimalBenesAux (
            long i,
            long budget,
            long nlev,
            const NTL::Vec< NTL::Vec< long >> & costTab,
            BenesMemoTable & memoTab )
```

6.2.3.350 optimalLower()

```
LowerMemoEntry helib::optimalLower (
            long order,
            bool good,
            long budget,
            long mid,
            LowerMemoTable & lowerMemoTable )
```

6.2.3.351 optimalUpperAux()

```
UpperMemoEntry helib::optimalUpperAux (
            const NTL::Vec< GenDescriptor > & vec,
            long i,
            long budget,
            long mid,
            UpperMemoTable & upperMemoTable,
            LowerMemoTable & lowerMemoTable )
```

6.2.3.352 ord()

```
long helib::ord (
            long N,
            long p )
```

Compute the highest power of p that divides N.

6.2.3.353 packConstant()

```
void helib::packConstant (
            zzX & result,
            unsigned long data,
            long nbits,
            const EncryptedArray & ea )
```

6.2.3.354 packConstants()

```
void helib::packConstants (
            zzX & result,
            const std::vector< unsigned long > & data,
            long nbits,
            const EncryptedArray & ea )
```

6.2.3.355 packedRecrypt() [1/4]

```
void helib::packedRecrypt (
            const CtPtrMat & m,
            const std::vector< zzX > & unpackConsts,
            const EncryptedArray & ea,
            long belowLvl = LONG_MAX )
```

6.2.3.356 packedRecrypt() [2/4]

```
void helib::packedRecrypt (
            const CtPtrs & a,
            const CtPtrs & b,
            std::vector< zzX > * unpackSlotEncoding )
```

Function for packed recryption to recrypt multiple numbers.

Parameters

a	first input of which to recrypt.
b	second input of which to recrypt.
unpackSlotEncoding	vector of constants for unpacking, as used in bootstrapping.

6.2.3.357 packedRecrypt() [3/4]

```
void helib::packedRecrypt (
            const CtPtrs & array,
            const std::vector< zzX > & unpackConsts,
            const EncryptedArray & ea,
            long belowLvl )
```

6.2.3.358 packedRecrypt() [4/4]

```
void helib::packedRecrypt (
            const CtPtrs & cPtrs,
            const std::vector< zzX > & unpackConsts,
            const EncryptedArray & ea )
```

6.2.3.359 PAlgebraLift() [1/2]

```
template<>
void helib::PAlgebraLift (
            const NTL::ZZX & phimx,
            const NTL::vec_zz_pX & lfactors,
            NTL::vec_zz_pX & factors,
            NTL::vec_zz_pX & crtc,
            long r )
```

6.2.3.360 PAlgebraLift() [2/2]

```
template<typename T >
void helib::PAlgebraLift (
            const NTL::ZZX & phimx,
            const T & lfactors,
            T & factors,
            T & crtc,
            long r )
```

6.2.3.361 phi_N()

```
long helib::phi_N (
            long N )
```

Compute Phi(N).

6.2.3.362 phiN() [1/2]

```
void helib::phiN (
            long & phiN,
            std::vector< long > & facts,
            long N )
```

Compute Phi(N) and also factorize N.

6.2.3.363 phiN() [2/2]

```
void helib::phiN (
            NTL::ZZ & phiN,
            std::vector< NTL::ZZ > & facts,
            const NTL::ZZ & N )
```

6.2.3.364 plaintextAutomorph() [1/2]

```
template<typename RX , typename type >
void helib::plaintextAutomorph (
            RX & b,
            const RX & a,
            long i,
            long j,
            const EncryptedArrayDerived< type > & ea )
```

6.2.3.365 plaintextAutomorph() [2/2]

```
template<typename RX , typename RXModulus >
void helib::plaintextAutomorph (
            RX & bb,
            const RX & a,
            long k,
            long m,
            const RXModulus & PhimX )
```

6.2.3.366 poly_comp()

```
template<typename RX >
bool helib::poly_comp (
            const RX & a,
            const RX & b )
```

6.2.3.367 polyEval() [1/2]

```
void helib::polyEval (
            Ctxt & ret,
            const NTL::Vec< Ctxt > & poly,
            const Ctxt & x )
```

Evaluate an encrypted polynomial on an encrypted input.

Parameters

out	*res*	to hold the return value
in	*poly*	the degree-d polynomial to evaluate
in	*x*	the point on which to evaluate

6.2.3.368 polyEval() [2/2]

```
void helib::polyEval (
            Ctxt & ret,
            NTL::ZZX poly,
            const Ctxt & x,
            long k = 0 )
```

Evaluate a cleartext polynomial on an encrypted input.

Parameters

out	*res*	to hold the return value
in	*poly*	the degree-d polynomial to evaluate
in	*x*	the point on which to evaluate

Parameters

in	*k*	optional optimization parameter, defaults to sqrt(d/2) rounded up or down to a power of two

6.2.3.369 polyEvalMod()

```
long helib::polyEvalMod (
            const NTL::ZZX & poly,
            long x,
            long p )
```

Evaluates a modular integer polynomial, returns poly(x) mod p.

6.2.3.370 PolyRed() [1/4]

```
void helib::PolyRed (
            NTL::ZZX & F,
            const NTL::ZZ & q,
            bool abs = false )  [inline]
```

6.2.3.371 PolyRed() [2/4]

```
void helib::PolyRed (
            NTL::ZZX & F,
            long q,
            bool abs = false )  [inline]
```

6.2.3.372 PolyRed() [3/4]

```
void helib::PolyRed (
            NTL::ZZX & out,
            const NTL::ZZX & in,
            const NTL::ZZ & q,
            bool abs = false )
```

6.2.3.373 PolyRed() [4/4]

```
void helib::PolyRed (
            NTL::ZZX & out,
            const NTL::ZZX & in,
            long q,
            bool abs = false )
```

Reduce all the coefficients of a polynomial modulo q.

When abs=false reduce to interval (-q/2,...,q/2), when abs=true reduce to [0,q). When abs=false and q=2, maintains the same sign as the input.

6.2.3.374 power()

```
void helib::power (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            long e )
```

6.2.3.375 pp_factorize()

```
void helib::pp_factorize (
            std::vector< long > & factors,
            long N )
```

Prime-power factorization.

6.2.3.376 ppInvert() [1/4]

```
void helib::ppInvert (
            NTL::mat_GF2 & X,
            const NTL::mat_GF2 & A,
            UNUSED long p,
            UNUSED long r )  [inline]
```

6.2.3.377 ppInvert() [2/4]

```
void helib::ppInvert (
            NTL::mat_GF2E & X,
            const NTL::mat_GF2E & A,
            UNUSED long p,
            UNUSED long r )  [inline]
```

6.2.3.378 ppInvert() [3/4]

```
void helib::ppInvert (
            NTL::mat_zz_p & X,
            const NTL::mat_zz_p & A,
            long p,
            long r )
```

Compute the inverse mod p^r of an n x n matrix.

NTL's current smallint modulus zz_p::modulus() is assumed to be p^r for p prime, r >= 1 integer. For the zz_pE variant also zz_pE::modulus() must be initialized. An error is raised if A is not invertible mod p.

6.2.3.379 ppInvert() [4/4]

```
void helib::ppInvert (
            NTL::mat_zz_pE & X,
            const NTL::mat_zz_pE & A,
            long p,
            long r )
```

6.2.3.380 ppsolve() [1/2]

```
void helib::ppsolve (
            NTL::vec_GF2E & x,
            const NTL::mat_GF2E & A,
            const NTL::vec_GF2E & b,
            long p,
            long r )
```

A version for GF2: must have p == 2 and r == 1.

6.2.3.381 ppsolve() [2/2]

```
void helib::ppsolve (
            NTL::vec_zz_pE & x,
            const NTL::mat_zz_pE & A,
            const NTL::vec_zz_pE & b,
            long p,
            long r )
```

Prime power solver.

A is an n x n matrix, b is a length n (row) vector, this function finds a solution for the matrix-vector equation x A = b. An error is raised if A is not invertible mod p.

NTL's current smallint modulus, zz_p::modulus(), is assumed to be p^r, for p prime, r >= 1 integer.

6.2.3.382 primroot()

```
long helib::primroot (
            long N,
            long phiN )
```

Find a primitive root modulo N.

6.2.3.383 print() [1/2]

```
void helib::print (
            const EncryptedArray & ea,
            std::ostream & s,
            const PlaintextArray & pa )
```

6.2.3.384 print() [2/2]

```
void helib::print (
            std::ostream & s,
            SplitNodePtr p,
            bool first )
```

6.2.3.385 print3D() [1/3]

```
template void helib::print3D (
            const HyperCube< long > & c )
```

6.2.3.386 print3D() [2/3]

```
template void helib::print3D (
            const HyperCube< NTL::zz_p > & c )
```

6.2.3.387 print3D() [3/3]

```
template<typename T >
void helib::print3D (
            const HyperCube< T > & c )
```

6.2.3.388 print_stats()

```
void helib::print_stats (
            std::ostream & s )
```

6.2.3.389 printAllTimers()

```
void helib::printAllTimers (
            std::ostream & str = std::cerr )
```

Print the value of all timers to stream.

6.2.3.390 printFlow()

```
void helib::printFlow (
            FlowGraph & fg )
```

6.2.3.391 printNamedTimer()

```
bool helib::printNamedTimer (
            std::ostream & str,
            const char * name )
```

6.2.3.392 printVec()

```
template<typename VEC >
std::ostream& helib::printVec (
            std::ostream & s,
            const VEC & v,
            long nCoeffs = 40 )
```

6.2.3.393 printZZX()

```
std::ostream& helib::printZZX (
            std::ostream & s,
            const NTL::ZZX & poly,
            long nCoeffs = 40 )  [inline]
```

6.2.3.394 ptr2nonNull()

```
template<typename T >
const T* helib::ptr2nonNull (
            std::initializer_list< const PtrVector< T > * > list )
```

6.2.3.395 random()

```
void helib::random (
            const EncryptedArray & ea,
            PlaintextArray & pa )
```

6.2.3.396 randomPerm()

```
void helib::randomPerm (
            Permut & perm,
            long n )
```

A random size-n permutation.

6.2.3.397 randomSlot()

```
template<typename Scheme >
Scheme::SlotType helib::randomSlot (
            const Context & context )
```

6.2.3.398 randomSlot< BGV >()

```
template<>
BGV::SlotType helib::randomSlot< BGV > (
            const Context & context )
```

6.2.3.399 randomSlot< CKKS >()

```
template<>
CKKS::SlotType helib::randomSlot< CKKS > (
            UNUSED const Context & context )
```

6.2.3.400 RandPoly()

```
NTL::ZZX helib::RandPoly (
            long n,
            const NTL::ZZ & p )
```

6.2.3.401 range() [1/2]

```
general_range<long> helib::range (
            long m,
            long n ) [inline]
```

6.2.3.402 range() [2/2]

```
general_range<long> helib::range (
            long n ) [inline]
```

6.2.3.403 rationalApprox() [1/2]

```
std::pair< long, long > helib::rationalApprox (
            double x,
            long denomBound = 0 )
```

6.2.3.404 rationalApprox() [2/2]

```
std::pair< NTL::ZZ, NTL::ZZ > helib::rationalApprox (
            NTL::xdouble x,
            NTL::xdouble denomBound = NTL::xdouble(0.0) )
```

6.2.3.405 rawDecrypt()

```
void helib::rawDecrypt (
            NTL::ZZX & plaintxt,
            const std::vector< NTL::ZZX > & zzParts,
            const DoubleCRT & sKey,
            long q = 0 )
```

6.2.3.406 read()

```
void helib::read (
            std::istream & s,
            ModuliSizes::Entry & e )
```

6.2.3.407 read_ntl_vec_long()

```
void helib::read_ntl_vec_long (
            std::istream & str,
            NTL::vec_long & vl )
```

6.2.3.408 read_raw_double()

```
double helib::read_raw_double (
            std::istream & str )
```

6.2.3.409 read_raw_int()

```
long helib::read_raw_int (
            std::istream & str )
```

6.2.3.410 read_raw_int32()

```
int helib::read_raw_int32 (
            std::istream & str )
```

6.2.3.411 read_raw_vector() [1/3]

```
template<typename T >
void helib::read_raw_vector (
            std::istream & str,
            std::vector< T > & v )
```

6.2.3.412 read_raw_vector() [2/3]

```
template<typename T >
void helib::read_raw_vector (
            std::istream & str,
            std::vector< T > & v,
            const Context & context )
```

6.2.3.413 read_raw_vector() [3/3]

```
template<typename T >
void helib::read_raw_vector (
            std::istream & str,
            std::vector< T > & v,
            T & init )
```

6.2.3.414 read_raw_vector< double >()

```
template<>
void helib::read_raw_vector< double > (
            std::istream & str,
            std::vector< double > & v )
```

6.2.3.415 read_raw_vector< long >()

```
template<>
void helib::read_raw_vector< long > (
            std::istream & str,
            std::vector< long > & v )
```

6.2.3.416 read_raw_xdouble()

```
NTL::xdouble helib::read_raw_xdouble (
            std::istream & str )
```

6.2.3.417 read_raw_ZZ()

```
void helib::read_raw_ZZ (
            std::istream & str,
            NTL::ZZ & zz )
```

6.2.3.418 readContextBase()

```
void helib::readContextBase (
            std::istream & s,
            unsigned long & m,
            unsigned long & p,
            unsigned long & r,
            std::vector< long > & gens,
            std::vector< long > & ords )
```

read [m p r gens ords] data, needed to construct context

read [m p r] data, needed to construct context

6.2.3.419 readContextBaseBinary()

```
void helib::readContextBaseBinary (
            std::istream & s,
            unsigned long & m,
            unsigned long & p,
            unsigned long & r,
            std::vector< long > & gens,
            std::vector< long > & ords )
```

read [m p r gens ords] data, needed to construct context

6.2.3.420 readContextBinary()

```
void helib::readContextBinary (
            std::istream & str,
            Context & context )
```

6.2.3.421 readEyeCatcher()

```
int helib::readEyeCatcher (
            std::istream & str,
            const char * expect )
```

6.2.3.422 readPubKeyBinary()

```
void helib::readPubKeyBinary (
            std::istream & str,
            PubKey & pk )
```

6.2.3.423 readSecKeyBinary()

```
void helib::readSecKeyBinary (
            std::istream & str,
            SecKey & sk )
```

6.2.3.424 realToEstimatedNoise()

```
double helib::realToEstimatedNoise (
            const Ctxt & ctxt,
            const SecKey & sk )
```

6.2.3.425 recordAutomorphVal()

```
void helib::recordAutomorphVal (
            long k ) [inline]
```

6.2.3.426 recordAutomorphVal2()

```
void helib::recordAutomorphVal2 (
            long k ) [inline]
```

6.2.3.427 reducedCount()

```
long helib::reducedCount (
            const std::list< long > & x,
            long n,
            bool * aux )
```

6.2.3.428 reduceModPhimX()

```
void helib::reduceModPhimX (
            zzX & poly,
            const PAlgebra & palg )
```

6.2.3.429 registerTimer()

```
void helib::registerTimer (
            FHEtimer * timer )
```

6.2.3.430 RelaxedInv() [1/2]

```
void helib::RelaxedInv (
            NTL::Mat< NTL::GF2 > & x,
            const NTL::Mat< NTL::GF2 > & a )
```

6.2.3.431 RelaxedInv() [2/2]

```
void helib::RelaxedInv (
            NTL::Mat< NTL::zz_p > & x,
            const NTL::Mat< NTL::zz_p > & a )
```

6.2.3.432 rem()

```
void helib::rem (
            NTL::zz_pX & r,
            const NTL::zz_pX & a,
            const zz_pXModulus1 & ff )
```

6.2.3.433 removeDups()

```
void helib::removeDups (
            std::list< long > & x,
            bool * aux )
```

6.2.3.434 repack() [1/2]

```
long helib::repack (
            const CtPtrs & packed,
            const CtPtrs & unpacked,
            const EncryptedArray & ea )
```

6.2.3.435 repack() [2/2]

```
void helib::repack (
            Ctxt & packed,
            const CtPtrs & unpacked,
            const EncryptedArray & ea )
```

6.2.3.436 replicate() [1/3]

```
template<typename Scheme >
void helib::replicate (
            const EncryptedArray & ,
            Ptxt< Scheme > & ptxt,
            long i )
```

Replicate single slot of a `Ptxt` object across all of its slots.

Template Parameters

Scheme	Encryption scheme used (must be `BGV` or `CKKS`).

Parameters

ptxt	Plaintext on which to do the replication.

Parameters

i	Position of the slot to replicate.

Returns

Reference to `*this` post replication.

6.2.3.437 replicate() [2/3]

```
void helib::replicate (
            const EncryptedArray & ea,
            Ctxt & ctx,
            long pos )
```

The value in slot #pos is replicated in all other slots. On an n-slot ciphertext, this algorithm performs O(log n) 1D rotations.

6.2.3.438 replicate() [3/3]

```
void helib::replicate (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            long i )
```

6.2.3.439 replicate0()

```
void helib::replicate0 (
            const EncryptedArray & ea,
            Ctxt & ctxt,
            long pos )
```

A lower-level routine. Same as replicate, but assumes all slots are zero except slot #pos.

6.2.3.440 replicateAll() [1/3]

```
void helib::replicateAll (
            const EncryptedArray & ea,
            const Ctxt & ctxt,
            ReplicateHandler * handler,
            long recBound = 64,
            RepAuxDim * repAuxPtr = nullptr )
```

replicateAll uses a hybrid strategy, combining the O(log n) strategy of the replicate method, with an O(1) strategy, which is faster but introduces more noise. This tradeoff is controlled by the parameter recBound:

- recBound $<$ 0: recursion to depth $|$recBound$|$ (faster, noisier)
- recBound ==0: no recursion (slower, less noise)
- recBound $>$ 0: the recursion depth is chosen heuristically, but is capped at recBound

The default value for recBound is 64, this ensures that the choice is based only on the heuristic, which will introduce noise corresponding to O(log log n) levels of recursion, but still gives an algorithm that theoretically runs in time O(n).

6.2.3.441 replicateAll() [2/3]

```
void helib::replicateAll (
            std::vector< Ctxt > & v,
            const EncryptedArray & ea,
            const Ctxt & ctxt,
            long recBound = 64,
            RepAuxDim * repAuxPtr = nullptr )
```

return the result as a std::vector of ciphertexts, mostly useful for debugging purposes (for real parameters would take a lot of memory)

6.2.3.442 replicateAll() [3/3]

```
template<typename Scheme >
void helib::replicateAll (
            std::vector< Ptxt< Scheme >> & v,
            const EncryptedArray & ,
            const Ptxt< Scheme > & ptxt )
```

Generate a vector of plaintexts with each slot replicated in each plaintext.

Template Parameters

Scheme	Encryption scheme used (must be BGV or CKKS).

Parameters

v	Vector of replicated plaintext slots.
ptxt	Plaintext whose slots will be replicated.

The order of the return vector agrees with the order of the slots. i.e. the `i`th plaintext in the return value is a replication of `*this[i]`.

6.2.3.443 replicateAllOrig()

```
void helib::replicateAllOrig (
            const EncryptedArray & ea,
            const Ctxt & ctxt,
            ReplicateHandler * handler,
            RepAux * repAuxPtr = nullptr )
```

This function is obsolete, and is kept for historical purposes only. It was a first attempt at implementing the O(1)-amortized algorithm, but is less efficient than the function above.

6.2.3.444 resetAllTimers()

```
void helib::resetAllTimers ( )
```

6.2.3.445 resize() [1/7]

```
template<typename T >
void helib::resize (
            NTL::Vec< T > & v,
            long sz )
```

6.2.3.446 resize() [2/7]

```
template<typename T >
void helib::resize (
            NTL::Vec< T > & v,
            long sz,
            const T & val )
```

6.2.3.447 resize() [3/7]

```
template<typename T >
void helib::resize (
            PtrMatrix< T > & v,
            long newSize )
```

6.2.3.448 resize() [4/7]

```
template<typename T >
void helib::resize (
            PtrVector< T > & v,
            long newSize,
            const T & val )
```

6.2.3.449 resize() [5/7]

```
template<typename T >
void helib::resize (
            PtrVector< T > & v,
            long newSize,
            const T * val )
```

6.2.3.450 resize() [6/7]

```
template<typename T >
void helib::resize (
            std::vector< T > & v,
            long sz )
```

6.2.3.451 resize() [7/7]

```
template<typename T >
void helib::resize (
            std::vector< T > & v,
            long sz,
            const T & val )
```

6.2.3.452 reverse()

```
template<typename T >
void helib::reverse (
            NTL::Vec< T > & v,
            long lo,
            long hi )
```

Reverse a vector in place.

6.2.3.453 RLWE()

```
double helib::RLWE (
            DoubleCRT & c0,
            DoubleCRT & c1,
            const DoubleCRT & s,
            long p,
            NTL::ZZ * prgSeed = nullptr )
```

Choose random c0,c1 such that c0+s∗c1 = p∗e for a short e Returns a high-probability bound on the L-infty norm of the canonical embedding

6.2.3.454 RLWE1()

```
double helib::RLWE1 (
            DoubleCRT & c0,
            const DoubleCRT & c1,
            const DoubleCRT & s,
            long p )
```

Same as RLWE, but assumes that c1 is already chosen by the caller.

6.2.3.455 rotate() [1/2]

```
void helib::rotate (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            long k )
```

6.2.3.456 rotate() [2/2]

```
template<typename T >
void helib::rotate (
            NTL::Vec< T > & v,
            long k )
```

Rotate a vector in place using swaps.

6.2.3.457 runningSums() [1/2]

```
void helib::runningSums (
            const EncryptedArray & ea,
            Ctxt & ctxt )
```

A ctxt that encrypts $(x_1, ..., x_n)$ is replaced by an encryption of $(y_1, ..., y_n)$, where $y_i = sum_{j \leq i} x_j$.

6.2.3.458 runningSums() [2/2]

```
void helib::runningSums (
            CtPtrs & v )
```

6.2.3.459 sameObject()

```
template<typename T1 , typename T2 >
bool helib::sameObject (
            const T1 * p1,
            const T2 * p2 )
```

Testing if two vectors point to the same object.

6.2.3.460 sampleGaussian() [1/4]

```
void helib::sampleGaussian (
            NTL::ZZX & poly,
            long n,
            double stdev )
```

6.2.3.461 sampleGaussian() [2/4]

```
void helib::sampleGaussian (
            std::vector< double > & dvec,
            long n,
            double stdev )
```

Choose a vector of continuous Gaussians.

6.2.3.462 sampleGaussian() [3/4]

```
double helib::sampleGaussian (
            zzX & poly,
            const Context & context,
            double stdev )
```

6.2.3.463 sampleGaussian() [4/4]

```
void helib::sampleGaussian (
            zzX & poly,
            long n,
            double stdev )
```

Sample polynomials with Gaussian coefficients.

6.2.3.464 sampleGaussianBounded()

```
double helib::sampleGaussianBounded (
            zzX & poly,
            const Context & context,
            double stdev )
```

6.2.3.465 sampleHWt() [1/3]

```
void helib::sampleHWt (
            NTL::ZZX & poly,
            long n,
            long Hwt = 100 )
```

6.2.3.466 sampleHWt() [2/3]

```
double helib::sampleHWt (
            zzX & poly,
            const Context & context,
            long Hwt = 100 )
```

6.2.3.467 sampleHWt() [3/3]

```
void helib::sampleHWt (
            zzX & poly,
            long n,
            long Hwt = 100 )
```

Sample a degree-(n-1) poly as above, with only Hwt nonzero coefficients.

6.2.3.468 sampleHWtBounded()

```
double helib::sampleHWtBounded (
            zzX & poly,
            const Context & context,
            long Hwt = 100 )
```

6.2.3.469 sampleHWtBoundedEffectiveBound()

```
double helib::sampleHWtBoundedEffectiveBound (
            const Context & context,
            long Hwt = 100 )
```

6.2.3.470 sampleSmall() [1/3]

```
void helib::sampleSmall (
            NTL::ZZX & poly,
            long n,
            double prob = 0.5 )
```

6.2.3.471 sampleSmall() [2/3]

```
double helib::sampleSmall (
            zzX & poly,
            const Context & context )
```

6.2.3.472 sampleSmall() [3/3]

```
void helib::sampleSmall (
            zzX & poly,
            long n,
            double prob = 0.5 )
```

Sample a degree-(n-1) poly, with -1/0/+1 coefficients. Each coefficients is +-1 with probability prob/2 each, and 0 with probability 1-prob. By default, pr[nonzero]=1/2.

6.2.3.473 sampleSmallBounded()

```
double helib::sampleSmallBounded (
            zzX & poly,
            const Context & context )
```

6.2.3.474 sampleUniform() [1/4]

```
NTL::xdouble helib::sampleUniform (
            NTL::ZZX & poly,
            const Context & context,
            const NTL::ZZ & B = NTL::ZZ(100L) )
```

6.2.3.475 sampleUniform() [2/4]

```
void helib::sampleUniform (
            NTL::ZZX & poly,
            long n,
            const NTL::ZZ & B = NTL::ZZ(100L) )
```

6.2.3.476 sampleUniform() [3/4]

```
double helib::sampleUniform (
            zzX & poly,
            const Context & context,
            long B = 100 )
```

6.2.3.477 sampleUniform() [4/4]

```
void helib::sampleUniform (
            zzX & poly,
            long n,
            long B = 100 )
```

Sample a degree-(n-1) ZZX, with coefficients uniform in [-B,B].

6.2.3.478 seekPastChar()

```
void helib::seekPastChar (
            std::istream & str,
            int cc )
```

Advance the input stream beyond white spaces and a single instance of the char cc.

6.2.3.479 setAutomorphVals()

```
void helib::setAutomorphVals (
            std::set< long > * aVals ) [inline]
```

6.2.3.480 setAutomorphVals2()

```
void helib::setAutomorphVals2 (
            std::set< long > * aVals ) [inline]
```

6.2.3.481 setDryRun()

```
bool helib::setDryRun (
            bool toWhat = true ) [inline]
```

6.2.3.482 setHyperColumn() [1/6]

```
template void helib::setHyperColumn (
            const NTL::Vec< long > & v,
            const CubeSlice< long > & s,
            long pos )
```

6.2.3.483 setHyperColumn() [2/6]

```
template void helib::setHyperColumn (
            const NTL::Vec< long > & v,
            const CubeSlice< long > & s,
            long pos,
            const long & val )
```

6.2.3.484 setHyperColumn() [3/6]

```
template void helib::setHyperColumn (
            const NTL::Vec< NTL::zz_p > & v,
            const CubeSlice< NTL::zz_p > & s,
            long pos )
```

6.2.3.485 setHyperColumn() [4/6]

```
template void helib::setHyperColumn (
            const NTL::Vec< NTL::zz_p > & v,
            const CubeSlice< NTL::zz_p > & s,
            long pos,
            const NTL::zz_p & val )
```

6.2.3.486 setHyperColumn() [5/6]

```
template<typename T >
void helib::setHyperColumn (
            const NTL::Vec< T > & v,
            const CubeSlice< T > & s,
            long pos )
```

setHyperColumn does the reverse of getHyperColumn, setting the column to the given vector

6.2.3.487 setHyperColumn() [6/6]

```
template<typename T >
void helib::setHyperColumn (
            const NTL::Vec< T > & v,
            const CubeSlice< T > & s,
            long pos,
            const T & val )
```

this version of setHyperColumn implicitly pads v with a default value, if v is too short

6.2.3.488 setLengthZero() [1/4]

```
template<typename T >
void helib::setLengthZero (
            NTL::Vec< T > & vec )
```

6.2.3.489 setLengthZero() [2/4]

```
template<typename T >
void helib::setLengthZero (
            PtrMatrix< T > & v )
```

6.2.3.490 setLengthZero() [3/4]

```
template<typename T >
void helib::setLengthZero (
            PtrVector< T > & v )
```

6.2.3.491 setLengthZero() [4/4]

```
template<typename T >
void helib::setLengthZero (
            std::vector< T > & vec )
```

6.2.3.492 setTimersOff()

```
void helib::setTimersOff ( ) [inline]
```

6.2.3.493 setTimersOn()

```
void helib::setTimersOn ( ) [inline]
```

6.2.3.494 setupDebugGlobals()

```
void helib::setupDebugGlobals (
            SecKey * debug_key,
            const std::shared_ptr< const EncryptedArray > & debug_ea,
            NTL::ZZX debug_ptxt = NTL::ZZX{} )  [inline]
```

Setup function for setting up the global debug variables.

Note

Works only if `HELIB_DEBUG` is defined. It does not do anything otherwise

6.2.3.495 shift()

```
void helib::shift (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            long k )
```

6.2.3.496 splitBinaryNums()

```
void helib::splitBinaryNums (
            CtPtrs & leftSplit,
            CtPtrs & rightSplit,
            const CtPtrs & input )
```

Splits a single binary number into two binary numbers `leftSplit` and `rightSplit`.

Split a binary number into two separate binary numbers.

Parameters

leftSplit	Left hand side of the split.
rightSplit	Right hand side of the split.
input	Binary number to be split.

Note

The size of `leftSplit` and `rightSplit` must sum to the size of `input`.

The location of the split is defined by the sizes of `leftSplit` and `rightSplit`.

6.2.3.497 sub()

```
void helib::sub (
            const EncryptedArray & ea,
            PlaintextArray & pa,
            const PlaintextArray & other )
```

6.2.3.498 subtractBinary()

```
void helib::subtractBinary (
            CtPtrs & difference,
            const CtPtrs & lhs,
            const CtPtrs & rhs,
            std::vector< zzX > * unpackSlotEncoding = nullptr )
```

Subtracts `rhs` from `lhs` where `lhs`, `rhs` are in 2's complement.

Parameters

difference	Reference to the difference post subtraction.
lhs	Left hand side of subtraction.
rhs	Right hand side of subtraction.
unpackSlotEncoding	vector of constants for unpacking, as used in bootstrapping.

Note

`lhs` and `rhs` must have the same size.

6.2.3.499 sumOfCoeffs() [1/3]

```
NTL::ZZ helib::sumOfCoeffs (
            const DoubleCRT & f )
```

6.2.3.500 sumOfCoeffs() [2/3]

```
NTL::ZZ helib::sumOfCoeffs (
            const NTL::ZZX & f )
```

6.2.3.501 sumOfCoeffs() [3/3]

```
long helib::sumOfCoeffs (
            const zzX & f )
```

6.2.3.502 swap() [1/2]

```
template<typename X , typename Cloner >
void helib::swap (
            cloned_ptr< X, Cloner > & x,
            cloned_ptr< X, Cloner > & y )
```

6.2.3.503 swap() [2/2]

```
template<typename X , typename Cloner >
void helib::swap (
            copied_ptr< X, Cloner > & x,
            copied_ptr< X, Cloner > & y )
```

6.2.3.504 tableLookup()

```
void helib::tableLookup (
            Ctxt & out,
            const std::vector< zzX > & table,
            const CtPtrs & idx,
            std::vector< zzX > * unpackSlotEncoding = nullptr )
```

The input is a plaintext table T[] and an array of encrypted bits I[], holding the binary representation of an index i into T. The output is the encrypted value T[i].

6.2.3.505 tableWriteIn()

```
void helib::tableWriteIn (
            const CtPtrs & table,
            const CtPtrs & idx,
            std::vector< zzX > * unpackSlotEncoding = nullptr )
```

The input is an encrypted table T[] and an array of encrypted bits I[], holding the binary representation of an index i into T. This function increments by one the entry T[i].

6.2.3.506 timer_compare()

```
bool helib::timer_compare (
            const FHEtimer * a,
            const FHEtimer * b )
```

6.2.3.507 to_ZZX()

```
NTL::ZZX helib::to_ZZX (
            const DoubleCRT & d )  [inline]
```

6.2.3.508 TofftRep_trunc() [1/2]

```
void helib::TofftRep_trunc (
            NTL::fftRep & y,
            const NTL::zz_pX & x,
            long k,
            long len )  [inline]
```

6.2.3.509 TofftRep_trunc() [2/2]

```
void helib::TofftRep_trunc (
            NTL::fftRep & y,
            const NTL::zz_pX & x,
            long k,
            UNUSED long len,
            long lo,
            long hi )  [inline]
```

6.2.3.510 totalProduct()

```
void helib::totalProduct (
            Ctxt & out,
            const std::vector< Ctxt > & v )
```

6.2.3.511 totalSums()

```
void helib::totalSums (
            const EncryptedArray & ea,
            Ctxt & ctxt )
```

6.2.3.512 traceMap()

```
void helib::traceMap (
            Ctxt & ctxt )
```

6.2.3.513 TraceMap()

```
void helib::TraceMap (
            NTL::GF2X & w,
            const NTL::GF2X & a,
            long d,
            const NTL::GF2XModulus & F,
            const NTL::GF2X & b )
```

6.2.3.514 unpack() [1/2]

```
long helib::unpack (
            const CtPtrs & unpacked,
            const CtPtrs & packed,
            const EncryptedArray & ea,
            const std::vector< zzX > & unpackSlotEncoding )
```

6.2.3.515 unpack() [2/2]

```
void helib::unpack (
            const CtPtrs & unpacked,
            const Ctxt & packed,
            const EncryptedArray & ea,
            const std::vector< zzX > & unpackSlotEncoding )
```

6.2.3.516 unpackSlots() [1/2]

```
void helib::unpackSlots (
            std::vector< unsigned long > & value,
            NTL::ZZX & pa,
            const EncryptedArray & ea ) [inline]
```

6.2.3.517 unpackSlots() [2/2]

```
void helib::unpackSlots (
            std::vector< unsigned long > & value,
            PlaintextArray & pa,
            const EncryptedArray & ea )
```

6.2.3.518 Vec_replicate()

```
template<typename T >
std::vector<T> helib::Vec_replicate (
            const T & a,
            long n )
```

6.2.3.519 vecCopy() [1/4]

```
template<typename T >
void helib::vecCopy (
            PtrVector< T > & v1,
            const PtrVector< T > & v2,
            long sizeLimit = 0 )
```

6.2.3.520 vecCopy() [2/4]

```
template<typename V , typename T >
void helib::vecCopy (
            PtrVector< T > & v1,
            const V & v2,
            long sizeLimit = 0 )
```

6.2.3.521 vecCopy() [3/4]

```
template<typename V , typename T >
void helib::vecCopy (
            V & v1,
            const PtrVector< T > & v2,
            long sizeLimit = 0 )
```

6.2.3.522 vecCopy() [4/4]

```
template<typename V1 , typename V2 >
void helib::vecCopy (
            V1 & v1,
            const V2 & v2,
            long sizeLimit = 0 )
```

6.2.3.523 vecRed() [1/2]

```
void helib::vecRed (
            NTL::Vec< NTL::ZZ > & out,
            const NTL::Vec< NTL::ZZ > & in,
            const NTL::ZZ & q,
            bool abs )
```

6.2.3.524 vecRed() [2/2]

```
void helib::vecRed (
            NTL::Vec< NTL::ZZ > & out,
            const NTL::Vec< NTL::ZZ > & in,
            long q,
            bool abs )
```

6.2.3.525 vector_replicate()

```
template<typename T >
std::vector<T> helib::vector_replicate (
            const T & a,
            long n )
```

6.2.3.526 vecToStr()

```
template<typename T >
std::string helib::vecToStr (
            const std::vector< T > & v )
```

6.2.3.527 Warning() [1/2]

```
void helib::Warning (
            const char * msg )  [inline]
```

6.2.3.528 Warning() [2/2]

```
void helib::Warning (
            const std::string & msg )  [inline]
```

6.2.3.529 write()

```
void helib::write (
            std::ostream & s,
            const ModuliSizes::Entry & e )
```

6.2.3.530 write_ntl_vec_long()

```
void helib::write_ntl_vec_long (
            std::ostream & str,
            const NTL::vec_long & vl,
            long intSize = BINIO_64BIT )
```

6.2.3.531 write_raw_double()

```
void helib::write_raw_double (
            std::ostream & str,
            const double d )
```

6.2.3.532 write_raw_int()

```
void helib::write_raw_int (
            std::ostream & str,
            long num )
```

6.2.3.533 write_raw_int32()

```
void helib::write_raw_int32 (
            std::ostream & str,
            int num )
```

6.2.3.534 write_raw_vector()

```
template<typename T >
void helib::write_raw_vector (
            std::ostream & str,
            const std::vector< T > & v )
```

6.2.3.535 write_raw_vector< double >()

```
template<>
void helib::write_raw_vector< double > (
            std::ostream & str,
            const std::vector< double > & v )
```

6.2.3.536 write_raw_vector< long >()

```
template<>
void helib::write_raw_vector< long > (
            std::ostream & str,
            const std::vector< long > & v )
```

6.2.3.537 write_raw_xdouble()

```
void helib::write_raw_xdouble (
            std::ostream & str,
            const NTL::xdouble xd )
```

6.2.3.538 write_raw_ZZ()

```
void helib::write_raw_ZZ (
            std::ostream & str,
            const NTL::ZZ & zz )
```

6.2.3.539 writeContextBase()

```
void helib::writeContextBase (
            std::ostream & s,
            const Context & context )
```

write [m p r gens ords] data

write [m p r] data

6.2.3.540 writeContextBaseBinary()

```
void helib::writeContextBaseBinary (
            std::ostream & str,
            const Context & context )
```

write [m p r gens ords] data

6.2.3.541 writeContextBinary()

```
void helib::writeContextBinary (
            std::ostream & str,
            const Context & context )
```

6.2.3.542 writeEyeCatcher()

```
void helib::writeEyeCatcher (
            std::ostream & str,
            const char * eye )
```

6.2.3.543 writePubKeyBinary()

```
void helib::writePubKeyBinary (
            std::ostream & str,
            const PubKey & pk )
```

6.2.3.544 writeSecKeyBinary()

```
void helib::writeSecKeyBinary (
            std::ostream & str,
            const SecKey & sk )
```

6.2.4 Variable Documentation

6.2.4.1 activeContext

```
Context * helib::activeContext = nullptr
```

6.2.4.2 CLOCK_SCALE

```
const unsigned long helib::CLOCK_SCALE = (unsigned long)CLOCKS_PER_SEC
```

6.2.4.3 dbg_ptxt

```
NTL::ZZX helib::dbg_ptxt
```

6.2.4.4 dbgEa

std::shared_ptr< const EncryptedArray > helib::dbgEa = nullptr

6.2.4.5 dbgKey

SecKey * helib::dbgKey = nullptr

6.2.4.6 erfc_inverse

const double helib::erfc_inverse[ ]

Initial value:

```
= {0,
                        0.6744897501960817432,
                        1.1503493803760081782,
                        1.5341205443525463117,
                        1.8627318674216514554,
                        2.1538746940614562129,
                        2.4175590162365050618,
                        2.6600674686174596585,
                        2.8856349124267571473,
                        3.0972690781987844623,
                        3.2971933456919633418,
                        3.4871041041144311068,
                        3.6683292851213230192,
                        3.8419306855019108708,
                        4.0087725941685849622,
                        4.1695693233491057549,
                        4.3249190408260462571,
                        4.4753284246542033544,
                        4.6212310014992471565,
                        4.7630010342678139569,
                        4.9009642079631930118}
```

6.2.4.7 fhe_force_chen_han

long helib::fhe_force_chen_han = 0

6.2.4.8 fhe_stats

bool helib::fhe_stats = false

6.2.4.9 fhe_test_force_bsgs

int helib::fhe_test_force_bsgs = 0

6.2.4.10 fhe_test_force_hoist

```
int helib::fhe_test_force_hoist = 0
```

6.2.4.11 fhe_watcher

```
int helib::fhe_watcher = 0
```

6.2.4.12 PI

```
const long double helib::PI
```

Initial value:

```
=
    3.1415926535897932384626433832795028841971693993751058209749445923078164L
```

6.2.4.13 printFlag

```
long helib::printFlag
```

6.2.4.14 replicateVerboseFlag

```
NTL_THREAD_LOCAL bool helib::replicateVerboseFlag = false
```

6.2.4.15 thinRecrypt_initial_level

```
long helib::thinRecrypt_initial_level
```

6.3 helib::FHEglobals Namespace Reference

Variables

- bool dryRun = false

  A dry-run flag The dry-run option disables most operations, to save time. This lets us quickly go over the evaluation of a circuit and estimate the resulting noise magnitude, without having to actually compute anything.
- std::set$<$ long $>$ $*$ automorphVals = nullptr

  A list of required automorphisms When non-nullptr, causes Ctxt::smartAutomorphism to just record the requested automorphism rather than actually performing it. This can be used to get a list of needed automorphisms for certain operations and then generate all these key-switching matrices. Should only be used in conjunction with dryRun=true.
- std::set$<$ long $>$ $*$ automorphVals2 = nullptr

6.3.1 Variable Documentation

6.3.1.1 automorphVals

`std::set< long > * helib::FHEglobals::automorphVals = nullptr`

A list of required automorphisms When non-nullptr, causes Ctxt::smartAutomorphism to just record the requested automorphism rather than actually performing it. This can be used to get a list of needed automorphisms for certain operations and then generate all these key-switching matrices. Should only be used in conjunction with dryRun=true.

6.3.1.2 automorphVals2

`std::set< long > * helib::FHEglobals::automorphVals2 = nullptr`

6.3.1.3 dryRun

`bool helib::FHEglobals::dryRun = false`

A dry-run flag The dry-run option disables most operations, to save time. This lets us quickly go over the evaluation of a circuit and estimate the resulting noise magnitude, without having to actually compute anything.

6.4 NTL Namespace Reference

6.5 std Namespace Reference

Chapter 7

Class Documentation

7.1 helib::add_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, const PlaintextArray &other)

7.1.1 Member Function Documentation

7.1.1.1 apply()

```
template<typename type >
static void helib::add_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            const PlaintextArray & other )  [inline], [static]
```

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

- /HElib/src/EncryptedArray.cpp

7.2 helib::AddDAG Class Reference

A class representing the logic of the order of bit products when adding two integers.

Public Member Functions

- void init (const CtPtrs &a, const CtPtrs &b)

    Build a plan to add a and b.
- AddDAG (const CtPtrs &a, const CtPtrs &b)
- void apply (CtPtrs &sum, const CtPtrs &a, const CtPtrs &b, long sizeLimit=0)

    Perform the actual addition.
- long lowLvl () const

    Returns the lowest level in this DAG.
- DAGnode ∗ findP (long i, long j) const

    Returns a pointer to the a 'p' node of index (i,j)
- DAGnode ∗ findQ (long i, long j) const

    Returns a pointer to the a 'q' node of index (i,j)

7.2.1 Detailed Description

A class representing the logic of the order of bit products when adding two integers.

Given two input arrays a[], b[], we build a DAG with each node representing a term either of the form p_{i,j} = \prod_{t=j}^i (a[t]+b[t]), or of the form q_{i,j} = (a[j]∗b[j]) ∗ \prod_{t=j+1}^i (a[t]+b[t]). The source nodes are of the forms (a[i]∗b[i]) and (a[i]+b[i]), and each non-source node has exactly two parents, whose product yields that node.

When building the DAG, we keep the level of each node as high as possible. For example we can set q_{i,j}=p_{i,k}∗q_{k-1,j} or q_{i,j}=p_{i,k+1}∗q_{k,j} (among other options), and we choose the option that results in the highest level. In addition, we try to minimize the number of nodes in the DAG that actually need to be computed while adding the two numbers (subject to still consuming as few levels as possible).

7.2.2 Constructor & Destructor Documentation

7.2.2.1 AddDAG()

```
helib::AddDAG::AddDAG (
            const CtPtrs & a,
            const CtPtrs & b )  [inline]
```

7.2.3 Member Function Documentation

7.2.3.1 apply()

```
void helib::AddDAG::apply (
            CtPtrs & sum,
            const CtPtrs & a,
            const CtPtrs & b,
            long sizeLimit = 0 )
```

Perform the actual addition.

Apply the DAG to actually compute the sum.

7.2.3.2 findP()

```
DAGnode* helib::AddDAG::findP (
            long i,
            long j ) const  [inline]
```

Returns a pointer to the a 'p' node of index (i,j)

7.2.3.3 findQ()

```
DAGnode* helib::AddDAG::findQ (
            long i,
            long j ) const  [inline]
```

Returns a pointer to the a 'q' node of index (i,j)

7.2.3.4 init()

```
void helib::AddDAG::init (
            const CtPtrs & a,
            const CtPtrs & b )
```

Build a plan to add a and b.

7.2.3.5 lowLvl()

```
long helib::AddDAG::lowLvl ( ) const  [inline]
```

Returns the lowest level in this DAG.

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

- /HElib/src/binaryArith.cpp

7.3 helib::PGFFT::aligned_allocator< T > Class Template Reference

```
#include <PGFFT.h>
```

Public Types

- using value_type = T

Public Member Functions

- aligned_allocator () noexcept
- template< class U >
  aligned_allocator (aligned_allocator< U > const &) noexcept
- value_type ∗ allocate (std::size_t n)
- void deallocate (value_type ∗p, std::size_t) noexcept
- template< class U >
  bool operator== (aligned_allocator< U > const &) noexcept
- template< class U >
  bool operator!= (aligned_allocator< U > const &y) noexcept

7.3.1 Member Typedef Documentation

7.3.1.1 value_type

```
template<class T >
using helib::PGFFT::aligned_allocator< T >::value_type = T
```

7.3.2 Constructor & Destructor Documentation

7.3.2.1 aligned_allocator() [1/2]

```
template<class T >
helib::PGFFT::aligned_allocator< T >::aligned_allocator ( )  [inline], [noexcept]
```

7.3.2.2 aligned_allocator() [2/2]

```
template<class T >
template<class U >
helib::PGFFT::aligned_allocator< T >::aligned_allocator (
            aligned_allocator< U > const & )  [inline], [noexcept]
```

7.3.3 Member Function Documentation

7.3.3.1 allocate()

```
template<class T >
value_type* helib::PGFFT::aligned_allocator< T >::allocate (
            std::size_t n )  [inline]
```

7.3.3.2 deallocate()

```
template<class T >
void helib::PGFFT::aligned_allocator< T >::deallocate (
            value_type * p,
            std::size_t  )  [inline], [noexcept]
```

7.3.3.3 operator"!=()

```
template<class T >
template<class U >
bool helib::PGFFT::aligned_allocator< T >::operator!= (
            aligned_allocator< U > const & y )  [inline], [noexcept]
```

7.3.3.4 operator==()

```
template<class T >
template<class U >
bool helib::PGFFT::aligned_allocator< T >::operator== (
            aligned_allocator< U > const &  )  [inline], [noexcept]
```

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

- /HElib/include/helib/PGFFT.h

7.4 helib::applyPerm_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, const NTL::Vec< long > &pi)

7.4.1 Member Function Documentation

7.4.1.1 apply()

```
template<typename type >
static void helib::applyPerm_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            const NTL::Vec< long > & pi )  [inline], [static]
```

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

- /HElib/src/EncryptedArray.cpp

7.5 helib::ArgMap Class Reference

Basic class for arg parsing. Example use:

`#include <ArgMap.h>`

Classes

- struct ArgProcessor

Public Types

- enum Separator { Separator::COLON, Separator::EQUALS, Separator::WHITESPACE }

Public Member Functions

- template<typename T >
  ArgMap & arg (const std::string &name, T &value)

  Add a new argument description Adds a new argument description with value of type T. Throws helib::RuntimeError if the arg key is duplicated or if the storing variable is used more than once.
- template<typename T >
  ArgMap & arg (const std::string &name, T &value, const std::string &doc)

  Add a new argument with docs Adds a new argument description with value of type T and docs. Throws helib::RuntimeError if the arg key is duplicated or if the storing variable is used more than once.
- template<typename T >
  ArgMap & arg (const std::string &name, T &value, const std::string &doc, const char ∗info)

  Add a new argument with docs and default description Adds a new argument description with value of type T, with docs and default description. Throws helib::RuntimeError if the arg key is duplicated or if the storing variable is used more than once.
- template<typename C >
  ArgMap & dots (C &container, const char ∗name)

  Adds variable number of positional arg types after defined arg types are exhausted. These are treated as optional.
- ArgMap & parse (int argc, char ∗∗argv)

  Parse the argv array Parse the argv array If it fails or -h is an argument it prints the usage and exits the program.
- ArgMap & parse (const std::string &filepath)

  Parse the configuration/parameters file Parsing a configuration file only functions with named arguments Parse the config file Throws RuntimeError on failure.

- ArgMap & optional ()

  Swaps to optional arg mode (default) Swaps to optional arg mode. Following arguments will be considered optional.
- ArgMap & required ()

  Swaps to required arg mode Swaps to required arg mode. Following arguments will be considered required.
- ArgMap & toggle (bool t=true)

  Swaps to toggle arg type Swaps to required arg mode. Following arguments will be considered of toggle type.
- ArgMap & named ()

  Swaps to named arg type (default) Swaps to required arg mode. Following arguments will be considered of named type.
- ArgMap & positional ()

  Swaps to positional arg type Swaps to required arg mode. Following arguments will be considered of positional type.
- ArgMap & helpArgs (const std::initializer_list< std::string > s)

  Provide custom help toggle args. (defaults are "-h", "--help") Overwrite default help toggle args to custom ones for parsing.
- ArgMap & helpArgs (const std::string s)
- ArgMap & diagnostics (std::ostream &ostrm=std::cout)

  Turns on diagnostics printout when parsing Swaps to required arg mode. Following arguments will be considered of positional type.
- ArgMap & separator (Separator s)

  Sets the key-value separator Sets the named args key-value pair separator character.
- ArgMap & note (const std::string &s)

  Adds a note to usage Adds a note to the arg usage description.
- void usage (const std::string &msg="") const

  Print usage and exit Prints the usage and exits the program.
- std::string doc () const

  Return arg docs Returns the argument documentation as a string.

7.5.1 Detailed Description

Basic class for arg parsing. Example use:

```
// Variables to be set by command line.
long p = 2;                                   // default values.
long m = 19;
bool t = false;
bool f = true;
std::string k = "Hello World";
ArgMap()                                      // (*) marks default.
  .required()                                 // set args to required.
  .positional()                               //
    .arg("p", p, "doc for p")                 //
    .arg("m", m, "doc for m", "undefined")    // special default info.
  .optional()                                 // swap to optional args (*).
  .named()                                    // named args (*) e.g.k=v.
  .separator(ArgMap::Separator::WHITESPACE)   // change separator to
    .arg("-k", k, "doc for k", "")            // whitespace ('=' is (*)).
    .note("an extra note")                    // no default value info.
  .toggle()                                   // add extra doc/note.
     .arg("-t", t, "doc for t", "")           // toggle flag sets bool true.
  .toggle(false)                              // toggle flag sets bool false.
     .arg("-f", f, "doc for f", "")           //
  .helpArgs({"--myhelp"})                     // changes default help flags
  .parse(argc, argv);                         // (*) is {"-h", "--help"}.
                                              // parses and overwrites values
```

7.5.2 Member Enumeration Documentation

7.5.2.1 Separator

enum helib::ArgMap::Separator [strong]

Enumerator

COLON	
EQUALS	
WHITESPACE	

7.5.3 Member Function Documentation

7.5.3.1 arg() [1/3]

```
template<typename T >
ArgMap & helib::ArgMap::arg (
            const std::string & name,
            T & value )
```

Add a new argument description Adds a new argument description with value of type T. Throws helib::RuntimeError if the arg key is duplicated or if the storing variable is used more than once.

Template Parameters

T	The type of the argument

Parameters

name	The argument name (key)
value	a variable where the argument will be stored. Also used as default value

Returns

A reference to the modified ArgMap object

7.5.3.2 arg() [2/3]

```
template<typename T >
ArgMap & helib::ArgMap::arg (
            const std::string & name,
            T & value,
            const std::string & doc )
```

Add a new argument with docs Adds a new argument description with value of type T and docs. Throws helib::RuntimeError if the arg key is duplicated or if the storing variable is used more than once.

Template Parameters

T	The type of the argument

Parameters

name	The argument name (key)
value	a variable where the argument will be stored. Also used as default value
doc1	Description of the argument used when displaying usage

Returns

A reference to the modified ArgMap object

7.5.3.3 arg() [3/3]

```
template<typename T >
ArgMap & helib::ArgMap::arg (
```

```
const std::string & name,
T & value,
const std::string & doc,
const char * info )
```

Add a new argument with docs and default description Adds a new argument description with value of type T, with docs and default description. Throws helib::RuntimeError if the arg key is duplicated or if the storing variable is used more than once.

Template Parameters

T	The type of the argument

Parameters

name	The argument name (key)
value	a variable where the argument will be stored. Also used as default value
doc1	Description of the argument used when displaying usage
info	The default value description (ignored if nullptr or "")

Returns

A reference to the modified ArgMap object

7.5.3.4 diagnostics()

```
ArgMap & helib::ArgMap::diagnostics (
            std::ostream & ostrm = std::cout )  [inline]
```

Turns on diagnostics printout when parsing Swaps to required arg mode. Following arguments will be considered of positional type.

Returns

A reference to the ArgMap object

7.5.3.5 doc()

```
std::string helib::ArgMap::doc ( ) const  [inline]
```

Return arg docs Returns the argument documentation as a string.

Returns

the argument documentation string

7.5.3.6 dots()

```
template<typename C >
ArgMap & helib::ArgMap::dots (
            C & container,
            const char * name )
```

Adds variable number of positional arg types after defined arg types are exhausted. These are treated as optional.

Parameters

container	holds the variable positional args. It must have a push_back method for insertion

Returns

A reference to the ArgMap object

7.5.3.7 helpArgs() [1/2]

```
ArgMap & helib::ArgMap::helpArgs (
        const std::initializer_list< std::string > s )  [inline]
```

Provide custom help toggle args. (defaults are "-h", "--help") Overwrite default help toggle args to custom ones for parsing.

Returns

A reference to the ArgMap object

7.5.3.8 helpArgs() [2/2]

```
ArgMap & helib::ArgMap::helpArgs (
        const std::string s )  [inline]
```

7.5.3.9 named()

```
ArgMap & helib::ArgMap::named ( )  [inline]
```

Swaps to named arg type (default) Swaps to required arg mode. Following arguments will be considered of named type.

Returns

A reference to the ArgMap object

7.5.3.10 note()

```
ArgMap & helib::ArgMap::note (
            const std::string & s )  [inline]
```

Adds a note to usage Adds a note to the arg usage description.

Parameters

s	The note string

Returns

A reference to the ArgMap object

7.5.3.11 optional()

```
ArgMap & helib::ArgMap::optional ( )  [inline]
```

Swaps to optional arg mode (default) Swaps to optional arg mode. Following arguments will be considered optional.

Returns

A reference to the ArgMap object

7.5.3.12 parse() [1/2]

```
ArgMap & helib::ArgMap::parse (
            const std::string & filepath )  [inline]
```

Parse the configuration/parameters file Parsing a configuration file only functions with named arguments Parse the config file Throws RuntimeError on failure.

Parameters

filepath	the config file path

Returns

A reference to the ArgMap object

7.5.3.13 parse() [2/2]

```
ArgMap & helib::ArgMap::parse (
            int argc,
            char ** argv )  [inline]
```

Parse the argv array Parse the argv array If it fails or -h is an argument it prints the usage and exits the program.

Parameters

argc	number of entries in argv
argv	array containing the arguments

Returns

A reference to the ArgMap object

7.5.3.14 positional()

```
ArgMap & helib::ArgMap::positional ( )  [inline]
```

Swaps to positional arg type Swaps to required arg mode. Following arguments will be considered of positional type.

Returns

A reference to the ArgMap object

7.5.3.15 required()

```
ArgMap & helib::ArgMap::required ( )  [inline]
```

Swaps to required arg mode Swaps to required arg mode. Following arguments will be considered required.

Returns

A reference to the ArgMap object

7.5.3.16 separator()

```
ArgMap & helib::ArgMap::separator (
            Separator s )  [inline]
```

Sets the key-value separator Sets the named args key-value pair separator character.

Parameters

s	the separator enum must be set either to COLON or EQUALS(default).

Returns

A reference to the ArgMap object

7.5.3.17 toggle()

```
ArgMap & helib::ArgMap::toggle (
            bool t = true ) [inline]
```

Swaps to toggle arg type Swaps to required arg mode. Following arguments will be considered of toggle type.

Returns

A reference to the ArgMap object

7.5.3.18 usage()

```
void helib::ArgMap::usage (
            const std::string & msg = "" ) const [inline]
```

Print usage and exit Prints the usage and exits the program.

Parameters

msg	An additional message to print before showing usage

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

- /HElib/include/helib/ArgMap.h

7.6 helib::ArgMap::ArgProcessor Struct Reference

```
#include <ArgMap.h>
```

Public Member Functions

- virtual ~ArgProcessor ()=default
- virtual ArgType getArgType ()=0
- virtual bool process (const std::string &s)=0

7.6.1 Constructor & Destructor Documentation

7.6.1.1 ~ArgProcessor()

```
virtual helib::ArgMap::ArgProcessor::~ArgProcessor ( )  [virtual], [default]
```

7.6.2 Member Function Documentation

7.6.2.1 getArgType()

```
virtual ArgType helib::ArgMap::ArgProcessor::getArgType ( )  [pure virtual]
```

7.6.2.2 process()

```
virtual bool helib::ArgMap::ArgProcessor::process (
            const std::string & s )  [pure virtual]
```

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

- /HElib/include/helib/ArgMap.h

7.7 helib::BasicAutomorphPrecon Class Reference

Pre-computation to speed many automorphism on the same ciphertext.

Public Member Functions

- BasicAutomorphPrecon (const Ctxt &_ctxt)
- std::shared_ptr< Ctxt > automorph (long k) const

7.7.1 Detailed Description

Pre-computation to speed many automorphism on the same ciphertext.

The expensive part of homomorphic automorphism is breaking the ciphertext parts into digits. The usual setting is we first rotate the ciphertext parts, then break them into digits. But when we apply many automorphisms it is faster to break the original ciphertext into digits, then rotate the digits (as opposed to first rotate, then break). An BasicAutomorphPrecon object breaks the original ciphertext and keeps the digits, then when you call automorph is only needs to apply the native automorphism and key switching to the digits, which is fast(er).

7.7.2 Constructor & Destructor Documentation

7.7.2.1 BasicAutomorphPrecon()

```
helib::BasicAutomorphPrecon::BasicAutomorphPrecon (
            const Ctxt & _ctxt )  [inline]
```

7.7.3 Member Function Documentation

7.7.3.1 automorph()

```
std::shared_ptr<Ctxt> helib::BasicAutomorphPrecon::automorph (
            long k ) const  [inline]
```

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

- /HElib/src/matmul.cpp

7.8 helib::BGV Struct Reference

Type for BGV scheme, to be used as template parameter.

`#include <Ptxt.h>`

Public Types

- using SlotType = PolyMod

  Slot type used for BGV plaintexts: `helib::PolyMod` i.e. an integer polynomial modulo p^r and G.

7.8.1 Detailed Description

Type for BGV scheme, to be used as template parameter.

7.8.2 Member Typedef Documentation

7.8.2.1 SlotType

```
using helib::BGV::SlotType = PolyMod
```

Slot type used for BGV plaintexts: `helib::PolyMod` i.e. an integer polynomial modulo p^r and G.

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

- /HElib/include/helib/Ptxt.h

7.9 helib::BipartitleGraph Class Reference

A bipartite flow graph.

`#include <matching.h>`

Public Member Functions

- void addEdge (long from, long to, long label, long color=0)
- void partitionToMatchings ()
- void printout ()

Public Attributes

- std::vector< LabeledVertex > left

7.9.1 Detailed Description

A bipartite flow graph.

7.9.2 Member Function Documentation

7.9.2.1 addEdge()

```
void helib::BipartitleGraph::addEdge (
            long from,
            long to,
            long label,
            long color = 0 )  [inline]
```

7.9.2.2 partitionToMatchings()

```
void helib::BipartitleGraph::partitionToMatchings ( )
```

7.9.2.3 printout()

```
void helib::BipartitleGraph::printout ( )
```

7.9.3 Member Data Documentation

7.9.3.1 left

```
std::vector<LabeledVertex> helib::BipartiteGraph::left
```

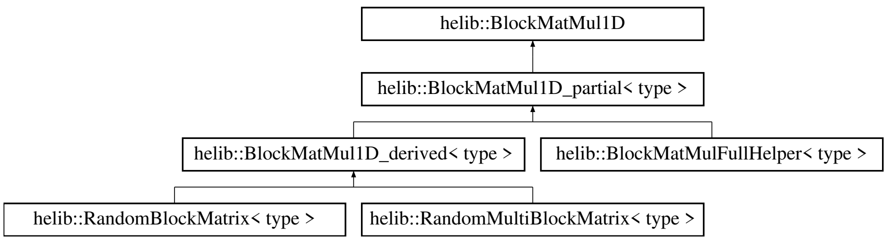
The documentation for this class was generated from the following files:

- /HElib/include/helib/matching.h
- /HElib/src/matching.cpp

7.10 helib::BlockMatMul1D Class Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::BlockMatMul1D:



Public Types

- typedef BlockMatMul1DExec ExecType

Public Member Functions

- virtual ~BlockMatMul1D ()
- virtual const EncryptedArray & getEA () const =0
- virtual long getDim () const =0

7.10.1 Member Typedef Documentation

7.10.1.1 ExecType

```
typedef BlockMatMul1DExec helib::BlockMatMul1D::ExecType
```

7.10.2 Constructor & Destructor Documentation

7.10.2.1 ∼BlockMatMul1D()

```
virtual helib::BlockMatMul1D::~BlockMatMul1D ( )  [inline], [virtual]
```

7.10.3 Member Function Documentation

7.10.3.1 getDim()

```
virtual long helib::BlockMatMul1D::getDim ( ) const  [pure virtual]
```

Implemented in helib::BlockMatMulFullHelper< type >, helib::RandomMultiBlockMatrix< type >, and helib::RandomBlockMatrix< ty

7.10.3.2 getEA()

```
virtual const EncryptedArray& helib::BlockMatMul1D::getEA ( ) const  [pure virtual]
```

Implemented in helib::BlockMatMulFullHelper< type >, helib::RandomMultiBlockMatrix< type >, and helib::RandomBlockMatrix< ty

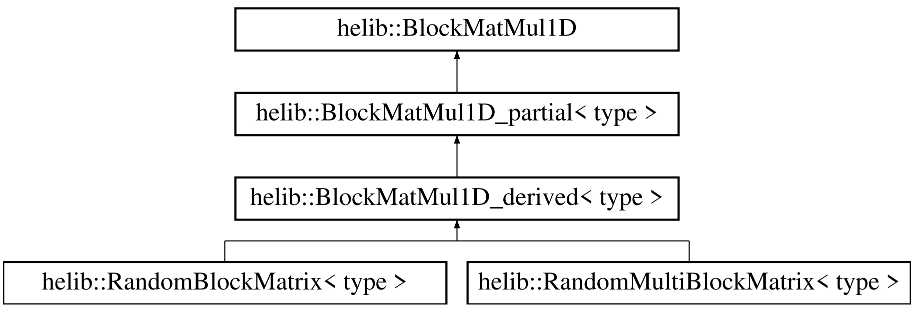
The documentation for this class was generated from the following file:

- /HElib/include/helib/matmul.h

7.11 helib::BlockMatMul1D_derived< type > Class Template Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::BlockMatMul1D_derived< type >:



Public Member Functions

- virtual bool multipleTransforms () const =0
- virtual bool get (mat_R &out, long i, long j, long k) const =0
- bool processDiagonal (std::vector< RX > &poly, long i, const EncryptedArrayDerived< type > &ea) const override

Additional Inherited Members

7.11.1 Member Function Documentation

7.11.1.1 get()

```
template<typename type >
virtual bool helib::BlockMatMul1D_derived< type >::get (
            mat_R & out,
            long i,
            long j,
            long k ) const  [pure virtual]
```

Implemented in helib::RandomMultiBlockMatrix< type >.

7.11.1.2 multipleTransforms()

```
template<typename type >
virtual bool helib::BlockMatMul1D_derived< type >::multipleTransforms ( ) const  [pure virtual]
```

Implemented in helib::RandomMultiBlockMatrix< type >, and helib::RandomBlockMatrix< type >.

7.11.1.3 processDiagonal()

```
template<typename type >
template bool helib::BlockMatMul1D_derived< type >::processDiagonal (
            std::vector< RX > & poly,
            long i,
            const EncryptedArrayDerived< type > & ea ) const  [override], [virtual]
```

Implements helib::BlockMatMul1D_partial< type >.

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

- /HElib/include/helib/matmul.h
- /HElib/src/matmul.cpp

7.12 helib::BlockMatMul1D_derived_impl< type > Struct Template Reference

Static Public Member Functions

- static bool processDiagonal1 (std::vector< RX > &poly, long i, const EncryptedArrayDerived< type > &ea, const BlockMatMul1D_derived< type > &mat)
- static bool processDiagonal2 (std::vector< RX > &poly, long idx, const EncryptedArrayDerived< type > &ea, const BlockMatMul1D_derived< type > &mat)
- static bool processDiagonal (std::vector< RX > &poly, long i, const EncryptedArrayDerived< type > &ea, const BlockMatMul1D_derived< type > &mat)

7.12.1 Member Function Documentation

7.12.1.1 processDiagonal()

```
template<typename type >
static bool helib::BlockMatMul1D_derived_impl< type >::processDiagonal (
            std::vector< RX > & poly,
            long i,
            const EncryptedArrayDerived< type > & ea,
            const BlockMatMul1D_derived< type > & mat )  [inline], [static]
```

7.12.1.2 processDiagonal1()

```
template<typename type >
static bool helib::BlockMatMul1D_derived_impl< type >::processDiagonal1 (
            std::vector< RX > & poly,
            long i,
            const EncryptedArrayDerived< type > & ea,
            const BlockMatMul1D_derived< type > & mat )  [inline], [static]
```

7.12.1.3 processDiagonal2()

```
template<typename type >
static bool helib::BlockMatMul1D_derived_impl< type >::processDiagonal2 (
            std::vector< RX > & poly,
            long idx,
            const EncryptedArrayDerived< type > & ea,
            const BlockMatMul1D_derived< type > & mat )  [inline], [static]
```

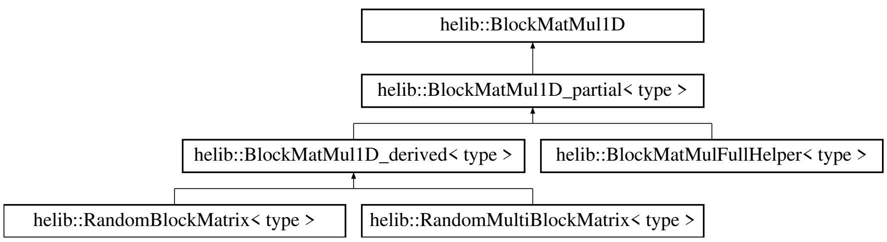
The documentation for this struct was generated from the following file:

- /HElib/src/matmul.cpp

7.13 helib::BlockMatMul1D_partial< type > Class Template Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::BlockMatMul1D_partial< type >:



Public Member Functions

- virtual bool processDiagonal (std::vector< RX > &poly, long i, const EncryptedArrayDerived< type > &ea) const =0

Additional Inherited Members

7.13.1 Member Function Documentation

7.13.1.1 processDiagonal()

```
template<typename type >
virtual bool helib::BlockMatMul1D_partial< type >::processDiagonal (
            std::vector< RX > & poly,
            long i,
            const EncryptedArrayDerived< type > & ea ) const  [pure virtual]
```

Implemented in helib::BlockMatMulFullHelper< type >, and helib::BlockMatMul1D_derived< type >.

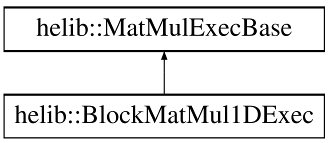
The documentation for this class was generated from the following file:

- /HElib/include/helib/matmul.h

7.14 helib::BlockMatMul1DExec Class Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::BlockMatMul1DExec:



Public Member Functions

- BlockMatMul1DExec (const BlockMatMul1D &mat, bool minimal=false)
- void mul (Ctxt &ctxt) const override
- void upgrade () override
- const EncryptedArray & getEA () const override

Public Attributes

- const EncryptedArray & ea
- long dim
- long D
- long d
- bool native
- long strategy
- ConstMultiplierCache cache
- ConstMultiplierCache cache1

7.14.1 Constructor & Destructor Documentation

7.14.1.1 BlockMatMul1DExec()

```
helib::BlockMatMul1DExec::BlockMatMul1DExec (
            const BlockMatMul1D & mat,
            bool minimal = false )  [explicit]
```

7.14.2 Member Function Documentation

7.14.2.1 getEA()

```
const EncryptedArray& helib::BlockMatMul1DExec::getEA ( ) const  [inline], [override], [virtual]
```

Implements helib::MatMulExecBase.

7.14.2.2 mul()

```
void helib::BlockMatMul1DExec::mul (
            Ctxt & ctxt ) const  [override], [virtual]
```

Implements helib::MatMulExecBase.

7.14.2.3 upgrade()

```
void helib::BlockMatMul1DExec::upgrade ( )  [inline], [override], [virtual]
```

Implements helib::MatMulExecBase.

7.14.3 Member Data Documentation

7.14.3.1 cache

```
ConstMultiplierCache helib::BlockMatMul1DExec::cache
```

7.14.3.2 cache1

```
ConstMultiplierCache helib::BlockMatMul1DExec::cache1
```

7.14.3.3 D

```
long helib::BlockMatMul1DExec::D
```

7.14.3.4 d

```
long helib::BlockMatMul1DExec::d
```

7.14.3.5 dim

```
long helib::BlockMatMul1DExec::dim
```

7.14.3.6 ea

```
const EncryptedArray& helib::BlockMatMul1DExec::ea
```

7.14.3.7 native

```
bool helib::BlockMatMul1DExec::native
```

7.14.3.8 strategy

```
long helib::BlockMatMul1DExec::strategy
```

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

- /HElib/include/helib/matmul.h
- /HElib/src/matmul.cpp

7.15 helib::BlockMatMul1DExec_construct< type > Struct Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, const BlockMatMul1D &mat_basetype, std::vector< std::shared_ptr< ConstMultiplier >> &vec, std::vector< std::shared_ptr< ConstMultiplier >> &vec1, long strategy)

7.15.1 Member Function Documentation

7.15.1.1 apply()

```
template<typename type >
static void helib::BlockMatMul1DExec_construct< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            const BlockMatMul1D & mat_basetype,
            std::vector< std::shared_ptr< ConstMultiplier >> & vec,
            std::vector< std::shared_ptr< ConstMultiplier >> & vec1,
            long strategy ) [inline], [static]
```

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

- /HElib/src/matmul.cpp

7.16 helib::BlockMatMulFullExec_construct< type >::BlockMatMulDimComp Struct Reference

Public Member Functions

- BlockMatMulDimComp (const EncryptedArrayDerived< type > *_ea)
- bool operator() (long i, long j)

Public Attributes

- const EncryptedArrayDerived< type > * ea

7.16.1 Constructor & Destructor Documentation

7.16.1.1 BlockMatMulDimComp()

```
template<typename type >
helib::BlockMatMulFullExec_construct< type >::BlockMatMulDimComp::BlockMatMulDimComp (
            const EncryptedArrayDerived< type > * _ea )  [inline]
```

7.16.2 Member Function Documentation

7.16.2.1 operator()()

```
template<typename type >
bool helib::BlockMatMulFullExec_construct< type >::BlockMatMulDimComp::operator() (
            long i,
            long j )  [inline]
```

7.16.3 Member Data Documentation

7.16.3.1 ea

```
template<typename type >
const EncryptedArrayDerived<type>* helib::BlockMatMulFullExec_construct< type >::BlockMat←
MulDimComp::ea
```

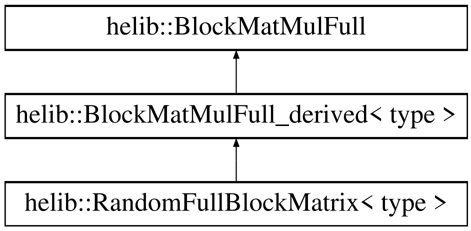
The documentation for this struct was generated from the following file:

- /HElib/src/matmul.cpp

7.17 helib::BlockMatMulFull Class Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::BlockMatMulFull:



Public Types

- typedef BlockMatMulFullExec ExecType

Public Member Functions

- virtual ~BlockMatMulFull ()
- virtual const EncryptedArray & getEA () const =0

7.17.1 Member Typedef Documentation

7.17.1.1 ExecType

```
typedef BlockMatMulFullExec helib::BlockMatMulFull::ExecType
```

7.17.2 Constructor & Destructor Documentation

7.17.2.1 ~BlockMatMulFull()

```
virtual helib::BlockMatMulFull::~BlockMatMulFull ( ) [inline], [virtual]
```

7.17.3 Member Function Documentation

7.17.3.1 getEA()

```
virtual const EncryptedArray& helib::BlockMatMulFull::getEA ( ) const [pure virtual]
```

Implemented in helib::RandomFullBlockMatrix< type >.

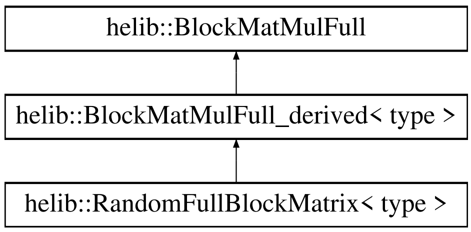
The documentation for this class was generated from the following file:

- /HElib/include/helib/matmul.h

7.18 helib::BlockMatMulFull_derived< type > Class Template Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::BlockMatMulFull_derived< type >:



Public Member Functions

- virtual bool get (mat_R &out, long i, long j) const =0

Additional Inherited Members

7.18.1 Member Function Documentation

7.18.1.1 get()

```
template<typename type >
virtual bool helib::BlockMatMulFull_derived< type >::get (
            mat_R & out,
            long i,
            long j ) const [pure virtual]
```

Implemented in helib::RandomFullBlockMatrix< type >.

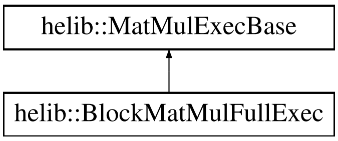
The documentation for this class was generated from the following file:

- /HElib/include/helib/matmul.h

7.19 helib::BlockMatMulFullExec Class Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::BlockMatMulFullExec:



Public Member Functions

- BlockMatMulFullExec (const BlockMatMulFull &mat, bool minimal=false)
- void mul (Ctxt &ctxt) const override
- void upgrade () override
- const EncryptedArray & getEA () const override
- long rec_mul (Ctxt &acc, const Ctxt &ctxt, long dim, long idx) const

Public Attributes

- const EncryptedArray & ea
- bool minimal
- std::vector< long > dims
- std::vector< BlockMatMul1DExec > transforms

7.19.1 Constructor & Destructor Documentation

7.19.1.1 BlockMatMulFullExec()

```
helib::BlockMatMulFullExec::BlockMatMulFullExec (
            const BlockMatMulFull & mat,
            bool minimal = false )   [explicit]
```

7.19.2 Member Function Documentation

7.19.2.1 getEA()

```
const EncryptedArray& helib::BlockMatMulFullExec::getEA ( ) const  [inline], [override], [virtual]
```

Implements helib::MatMulExecBase.

7.19.2.2 mul()

```
void helib::BlockMatMulFullExec::mul (
            Ctxt & ctxt ) const  [override], [virtual]
```

Implements helib::MatMulExecBase.

7.19.2.3 rec_mul()

```
long helib::BlockMatMulFullExec::rec_mul (
            Ctxt & acc,
            const Ctxt & ctxt,
            long dim,
            long idx ) const
```

7.19.2.4 upgrade()

```
void helib::BlockMatMulFullExec::upgrade ( )  [inline], [override], [virtual]
```

Implements helib::MatMulExecBase.

7.19.3 Member Data Documentation

7.19.3.1 dims

```
std::vector<long> helib::BlockMatMulFullExec::dims
```

7.19.3.2 ea

```
const EncryptedArray& helib::BlockMatMulFullExec::ea
```

7.19.3.3 minimal

```
bool helib::BlockMatMulFullExec::minimal
```

7.19.3.4 transforms

```
std::vector<BlockMatMul1DExec> helib::BlockMatMulFullExec::transforms
```

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

- /HElib/include/helib/matmul.h
- /HElib/src/matmul.cpp

7.20 helib::BlockMatMulFullExec_construct< type > Struct Template Reference

Classes

- struct BlockMatMulDimComp

Static Public Member Functions

- static long rec_mul (long dim, long idx, const std::vector< long > &idxes, std::vector< BlockMatMul1DExec > &transforms, bool minimal, const std::vector< long > &dims, const EncryptedArray &ea_basetype, const EncryptedArrayDerived< type > &ea, const BlockMatMulFull_derived< type > &mat)
- static void apply (const EncryptedArrayDerived< type > &ea, const EncryptedArray &ea_basetype, const BlockMatMulFull &mat_basetype, std::vector< BlockMatMul1DExec > &transforms, bool minimal, std::vector< long > &dims)

7.20.1 Member Function Documentation

7.20.1.1 apply()

```
template<typename type >
static void helib::BlockMatMulFullExec_construct< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            const EncryptedArray & ea_basetype,
            const BlockMatMulFull & mat_basetype,
            std::vector< BlockMatMul1DExec > & transforms,
            bool minimal,
            std::vector< long > & dims ) [inline], [static]
```

7.20.1.2 rec_mul()

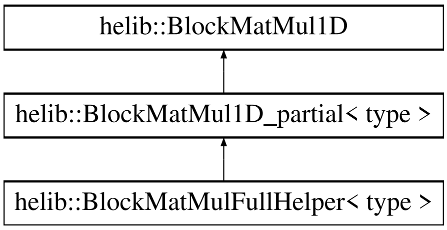
```
template<typename type >
static long helib::BlockMatMulFullExec_construct< type >::rec_mul (
            long dim,
            long idx,
            const std::vector< long > & idxes,
            std::vector< BlockMatMul1DExec > & transforms,
            bool minimal,
            const std::vector< long > & dims,
            const EncryptedArray & ea_basetype,
            const EncryptedArrayDerived< type > & ea,
            const BlockMatMulFull_derived< type > & mat )  [inline], [static]
```

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

- /HElib/src/matmul.cpp

7.21 helib::BlockMatMulFullHelper< type > Class Template Reference

Inheritance diagram for helib::BlockMatMulFullHelper< type >:



Public Member Functions

- BlockMatMulFullHelper (const EncryptedArray &_ea_basetype, const BlockMatMulFull_derived< type > &↩ _mat, const std::vector< long > &_init_idxes, long _dim)
- bool processDiagonal (std::vector< RX > &poly, long offset, const EncryptedArrayDerived< type > &ea) const override
- const EncryptedArray & getEA () const override
- long getDim () const override

Public Attributes

- const EncryptedArray & ea_basetype
- const BlockMatMulFull_derived< type > & mat
- std::vector< long > init_idxes
- long dim

Additional Inherited Members

7.21.1 Constructor & Destructor Documentation

7.21.1.1 BlockMatMulFullHelper()

```
template<typename type >
helib::BlockMatMulFullHelper< type >::BlockMatMulFullHelper (
            const EncryptedArray & _ea_basetype,
            const BlockMatMulFull_derived< type > & _mat,
            const std::vector< long > & _init_idxes,
            long _dim ) [inline]
```

7.21.2 Member Function Documentation

7.21.2.1 getDim()

```
template<typename type >
long helib::BlockMatMulFullHelper< type >::getDim ( ) const [inline], [override], [virtual]
```

Implements helib::BlockMatMul1D.

7.21.2.2 getEA()

```
template<typename type >
const EncryptedArray& helib::BlockMatMulFullHelper< type >::getEA ( ) const [inline], [override],
[virtual]
```

Implements helib::BlockMatMul1D.

7.21.2.3 processDiagonal()

```
template<typename type >
bool helib::BlockMatMulFullHelper< type >::processDiagonal (
            std::vector< RX > & poly,
            long offset,
            const EncryptedArrayDerived< type > & ea ) const [inline], [override], [virtual]
```

Implements helib::BlockMatMul1D_partial< type >.

7.21.3 Member Data Documentation

7.21.3.1 dim

```
template<typename type >
long helib::BlockMatMulFullHelper< type >::dim
```

7.21.3.2 ea_basetype

```
template<typename type >
const EncryptedArray& helib::BlockMatMulFullHelper< type >::ea_basetype
```

7.21.3.3 init_idxes

```
template<typename type >
std::vector<long> helib::BlockMatMulFullHelper< type >::init_idxes
```

7.21.3.4 mat

```
template<typename type >
const BlockMatMulFull_derived<type>& helib::BlockMatMulFullHelper< type >::mat
```

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

- /HElib/src/matmul.cpp

7.22 helib::CKKS Struct Reference

Type for CKKS scheme, to be used as template parameter.

```
#include <Ptxt.h>
```

Public Types

- using SlotType = std::complex< double >

  Slot type used for CKKS plaintexts: `std::complex<double>`*.*

7.22.1 Detailed Description

Type for CKKS scheme, to be used as template parameter.

7.22.2 Member Typedef Documentation

7.22.2.1 SlotType

```
using helib::CKKS::SlotType = std::complex<double>
```

Slot type used for CKKS plaintexts: `std::complex<double>`.

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

- /HElib/include/helib/Ptxt.h

7.23 helib::Cmodulus Class Reference

Provides FFT and iFFT routines modulo a single-precision prime.

`#include <CModulus.h>`

Public Member Functions

- Cmodulus ()
  Default constructor.
- Cmodulus (const Cmodulus &other)
- Cmodulus (const PAlgebra &zms, long qq, long rt)
  Constructor.
- Cmodulus & operator= (const Cmodulus &other)
  Copy assignment operator.
- const PAlgebra & getZMStar () const
- unsigned long getM () const
- unsigned long getPhiM () const
- long getQ () const
- NTL::mulmod_t getQInv () const
- long getRoot () const
- const zz_pXModulus1 & getPhimX () const
- void restoreModulus () const
  Restore NTL's current modulus.
- void FFT (NTL::vec_long &y, const NTL::ZZX &x) const
- void FFT (NTL::vec_long &y, const zzX &x) const
- void FFT_aux (NTL::vec_long &y, NTL::zz_pX &tmp) const
- void iFFT (NTL::zz_pX &x, const NTL::vec_long &y) const

Static Public Member Functions

- static NTL::zz_pX & getScratch_zz_pX ()
- static NTL::Vec< long > & getScratch_vec_long ()
- static NTL::fftRep & getScratch_fftRep (long k)

7.23.1 Detailed Description

Provides FFT and iFFT routines modulo a single-precision prime.

On initialization, it initializes NTL's zz_pContext for this q and computes a 2m-th root of unity r mod q and also r^{-1} mod q. Thereafter this class provides FFT and iFFT routines that converts between time & frequency domains. Some tables are computed the first time that each directions is called, which are then used in subsequent computations.

The "time domain" polynomials are represented as ZZX, which are reduced modulo Phi_m(X). The "frequency domain" are just vectors of integers (vec_long), that store only the evaluation in primitive m-th roots of unity.

7.23.2 Constructor & Destructor Documentation

7.23.2.1 Cmodulus() `[1/3]`

```
helib::Cmodulus::Cmodulus ( )  [inline]
```

Default constructor.

7.23.2.2 Cmodulus() `[2/3]`

```
helib::Cmodulus::Cmodulus (
            const Cmodulus & other )  [inline]
```

7.23.2.3 Cmodulus() `[3/3]`

```
helib::Cmodulus::Cmodulus (
            const PAlgebra & zms,
            long qq,
            long rt )
```

Constructor.

Note

Specify m and q, and optionally also the root if q == 0, then the current context is used

7.23.3 Member Function Documentation

7.23.3.1 FFT() [1/2]

```
void helib::Cmodulus::FFT (
            NTL::vec_long & y,
            const NTL::ZZX & x ) const
```

7.23.3.2 FFT() [2/2]

```
void helib::Cmodulus::FFT (
            NTL::vec_long & y,
            const zzX & x ) const
```

7.23.3.3 FFT_aux()

```
void helib::Cmodulus::FFT_aux (
            NTL::vec_long & y,
            NTL::zz_pX & tmp ) const
```

7.23.3.4 getM()

```
unsigned long helib::Cmodulus::getM ( ) const [inline]
```

7.23.3.5 getPhiM()

```
unsigned long helib::Cmodulus::getPhiM ( ) const [inline]
```

7.23.3.6 getPhimX()

```
const zz_pXModulus1& helib::Cmodulus::getPhimX ( ) const [inline]
```

7.23.3.7 getQ()

```
long helib::Cmodulus::getQ ( ) const [inline]
```

7.23.3.8 getQInv()

```
NTL::mulmod_t helib::Cmodulus::getQInv ( ) const [inline]
```

7.23.3.9 getRoot()

```
long helib::Cmodulus::getRoot ( ) const [inline]
```

7.23.3.10 getScratch_fftRep()

```
NTL::fftRep & helib::Cmodulus::getScratch_fftRep (
             long k ) [static]
```

7.23.3.11 getScratch_vec_long()

```
NTL::Vec< long > & helib::Cmodulus::getScratch_vec_long ( ) [static]
```

7.23.3.12 getScratch_zz_pX()

```
NTL::zz_pX & helib::Cmodulus::getScratch_zz_pX ( ) [static]
```

7.23.3.13 getZMStar()

```
const PAlgebra& helib::Cmodulus::getZMStar ( ) const [inline]
```

7.23.3.14 iFFT()

```
void helib::Cmodulus::iFFT (
             NTL::zz_pX & x,
             const NTL::vec_long & y ) const
```

7.23.3.15 operator=()

```
Cmodulus & helib::Cmodulus::operator= (
             const Cmodulus & other )
```

Copy assignment operator.

7.23.3.16 restoreModulus()

```
void helib::Cmodulus::restoreModulus ( ) const  [inline]
```

Restore NTL's current modulus.

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

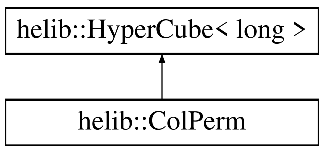
- /HElib/include/helib/CModulus.h
- /HElib/src/CModulus.cpp

7.24 helib::ColPerm Class Reference

Permuting a single dimension (column) of a hypercube.

`#include <permutations.h>`

Inheritance diagram for helib::ColPerm:



Public Member Functions

- ColPerm (const CubeSignature &_sig)
- long getPermDim () const
- void setPermDim (long _dim)
- void makeExplicit (Permut &out) const
- long getShiftAmounts (Permut &out) const
- void getBenesShiftAmounts (NTL::Vec< Permut > &out, NTL::Vec< bool > &idID, const NTL::Vec< long > &benesLvls) const
- void printout (std::ostream &s)

    A test/debugging method.

7.24.1 Detailed Description

Permuting a single dimension (column) of a hypercube.

ColPerm is derived from a HyperCube<long>, and it uses the cube object to store the actual permutation data. The interpretation of this data, however, depends on the data member dim.

The cube is partitioned into columns of size n = getDim(dim): a single column consists of the n entries whose indices i have the same coordinates in all dimensions other than dim. The entries in any such column form a permutation on [0..n).

For a given ColPerm perm, one way to access each column is as follows: for slice_index = [0..perm.getProd(0, dim)) CubeSlice slice(perm, slice_index, dim) for col_index = [0..perm.getProd(dim+1)) getHyperColumn(column, slice, col_index)

Another way is to use the getCoord and addCoord methods.

For example, permuting a 2x3x2 cube along dim=1 (the 2nd dimension), we could have the data std::vector as [1 1 0 2 2 0 2 0 1 1 0 2]. This means the four columns are permuted by the permutations [1 0 2] [1 2 0] [2 1 0] [0 1 2]. Written explicitly, we get: [2 3 0 5 4 1 10 7 8 9 6 11].

Another representation that we provide is by "shift amount": how many slots each element needs to move inside its small permutation. For the example above, this will be: [1 -1 0] [2 -1 -1] [2 0 -2] [0 0 0] so we write the permutation as [1 1 -1 1 0 -2 2 0 0 0 -2 0].

7.24.2 Constructor & Destructor Documentation

7.24.2.1 ColPerm()

```
helib::ColPerm::ColPerm (
            const CubeSignature & _sig )  [inline], [explicit]
```

7.24.3 Member Function Documentation

7.24.3.1 getBenesShiftAmounts()

```
void helib::ColPerm::getBenesShiftAmounts (
            NTL::Vec< Permut > & out,
            NTL::Vec< bool > & idID,
            const NTL::Vec< long > & benesLvls ) const
```

Get multiple layers of a Benes permutation network. Returns in out[i][j] the shift amount to move item j in the i'th layer. Also isID[i]=true if the i'th layer is the identity (i.e., contains only 0 shift amounts).

7.24.3.2 getPermDim()

```
long helib::ColPerm::getPermDim ( ) const  [inline]
```

7.24.3.3 getShiftAmounts()

```
long helib::ColPerm::getShiftAmounts (
            Permut & out ) const
```

For each position in the data std::vector, compute how many slots it should be shifted inside its small permutation. Returns zero if all the shift amounts are zero, nonzero values otherwise.

7.24.3.4 makeExplicit()

```
void helib::ColPerm::makeExplicit (
            Permut & out ) const
```

7.24.3.5 printout()

```
void helib::ColPerm::printout (
            std::ostream & s )  [inline]
```

A test/debugging method.

7.24.3.6 setPermDim()

```
void helib::ColPerm::setPermDim (
            long _dim )  [inline]
```

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

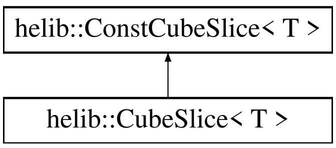
- /HElib/include/helib/permutations.h
- /HElib/src/permutations.cpp

7.25 helib::ConstCubeSlice< T > Class Template Reference

A constant lower-dimension slice of a hypercube.

```
#include <hypercube.h>
```

Inheritance diagram for helib::ConstCubeSlice< T >:



Public Member Functions

- ConstCubeSlice (const HyperCube< T > &_cube)

  initialize the slice to the full cube
- ConstCubeSlice (const NTL::Vec< T > &_data, const CubeSignature &_sig)
- ConstCubeSlice (const ConstCubeSlice &bigger, long i, long _dimOffset=1)
- ConstCubeSlice (const HyperCube< T > &_cube, long i, long _dimOffset=1)
- const CubeSignature & getSig () const

  const ref to signature
- long getSize () const

  total size
- long getNumDims () const

  number of dimensions
- long getDim (long d) const

  size of dimension d
- long getProd (long d) const

  product of sizes of dimensions d, d+1, ...
- long getProd (long from, long to) const

  product of sizes of dimensions from, from+1, ..., to-1
- long getCoord (long i, long d) const

  get coordinate in dimension d of index i
- long addCoord (long i, long d, long offset) const

  add offset to coordinate in dimension d of index i
- long numSlices (long d=1) const

  number of slices
- long sliceSize (long d=1) const

  size of one slice
- long numCols () const

  number of columns
- const T & at (long i) const

  read-only reference to element at position i, with bounds check
- const T & operator[ ] (long i) const

  read-only reference to element at position i, without bounds check

7.25.1 Detailed Description

template<typename T>
class helib::ConstCubeSlice< T >

A constant lower-dimension slice of a hypercube.

A ConstCubeSlice acts like a pointer to a lower dimensional constant subcube of a hypercube. It is initialized using a reference to a hypercube, which must remain alive during the lifetime of the slice, to prevent dangling pointers. The subclass CubeSlice works also with non-constant cubes and subcubes.

In addition, for greater flexibility, a "slice" may be initialized with a vector and a signature, rather than a cube

7.25.2 Constructor & Destructor Documentation

7.25.2.1 ConstCubeSlice() [1/4]

```
template<typename T >
helib::ConstCubeSlice< T >::ConstCubeSlice (
            const HyperCube< T > & _cube )  [inline], [explicit]
```

initialize the slice to the full cube

7.25.2.2 ConstCubeSlice() [2/4]

```
template<typename T >
helib::ConstCubeSlice< T >::ConstCubeSlice (
            const NTL::Vec< T > & _data,
            const CubeSignature & _sig )  [inline]
```

7.25.2.3 ConstCubeSlice() [3/4]

```
template<typename T >
helib::ConstCubeSlice< T >::ConstCubeSlice (
            const ConstCubeSlice< T > & bigger,
            long i,
            long _dimOffset = 1 )
```

initialize the slice to point to the i-th subcube (with some given dimension offset) of the cube pointed to by _cube or bigger.

7.25.2.4 ConstCubeSlice() [4/4]

```
template<typename T >
helib::ConstCubeSlice< T >::ConstCubeSlice (
            const HyperCube< T > & _cube,
            long i,
            long _dimOffset = 1 )
```

7.25.3 Member Function Documentation

7.25.3.1 addCoord()

```
template<typename T >
long helib::ConstCubeSlice< T >::addCoord (
            long i,
            long d,
            long offset ) const  [inline]
```

add offset to coordinate in dimension d of index i

7.25.3.2 at()

```
template<typename T >
const T& helib::ConstCubeSlice< T >::at (
            long i ) const  [inline]
```

read-only reference to element at position i, with bounds check

7.25.3.3 getCoord()

```
template<typename T >
long helib::ConstCubeSlice< T >::getCoord (
            long i,
            long d ) const  [inline]
```

get coordinate in dimension d of index i

7.25.3.4 getDim()

```
template<typename T >
long helib::ConstCubeSlice< T >::getDim (
            long d ) const  [inline]
```

size of dimension d

7.25.3.5 getNumDims()

```
template<typename T >
long helib::ConstCubeSlice< T >::getNumDims ( ) const  [inline]
```

number of dimensions

7.25.3.6 getProd() [1/2]

```
template<typename T >
long helib::ConstCubeSlice< T >::getProd (
            long d ) const  [inline]
```

product of sizes of dimensions d, d+1, ...

7.25.3.7 getProd() [2/2]

```
template<typename T >
long helib::ConstCubeSlice< T >::getProd (
            long from,
            long to ) const  [inline]
```

product of sizes of dimensions from, from+1, ..., to-1

7.25.3.8 getSig()

```
template<typename T >
const CubeSignature& helib::ConstCubeSlice< T >::getSig ( ) const  [inline]
```

const ref to signature

7.25.3.9 getSize()

```
template<typename T >
long helib::ConstCubeSlice< T >::getSize ( ) const  [inline]
```

total size

7.25.3.10 numCols()

```
template<typename T >
long helib::ConstCubeSlice< T >::numCols ( ) const  [inline]
```

number of columns

7.25.3.11 numSlices()

```
template<typename T >
long helib::ConstCubeSlice< T >::numSlices (
            long d = 1 ) const  [inline]
```

number of slices

7.25.3.12 operator[]()

```
template<typename T >
const T& helib::ConstCubeSlice< T >::operator[] (
             long i ) const  [inline]
```

read-only reference to element at position i, without bounds check

7.25.3.13 sliceSize()

```
template<typename T >
long helib::ConstCubeSlice< T >::sliceSize (
             long d = 1 ) const  [inline]
```

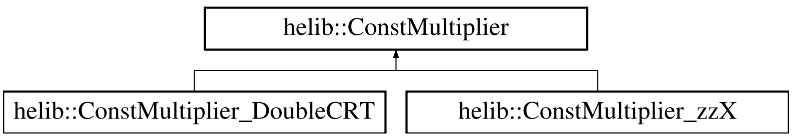
size of one slice

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

- /HElib/include/helib/hypercube.h
- /HElib/src/hypercube.cpp

7.26 helib::ConstMultiplier Struct Reference

Inheritance diagram for helib::ConstMultiplier:



Public Member Functions

- virtual ∼ConstMultiplier ()
- virtual void mul (Ctxt &ctxt) const =0
- virtual std::shared_ptr< ConstMultiplier > upgrade (const Context &context) const =0

7.26.1 Constructor & Destructor Documentation

7.26.1.1 ∼ConstMultiplier()

```
virtual helib::ConstMultiplier::~ConstMultiplier ( )  [inline], [virtual]
```

7.26.2 Member Function Documentation

7.26.2.1 mul()

```
virtual void helib::ConstMultiplier::mul (
            Ctxt & ctxt ) const  [pure virtual]
```

Implemented in helib::ConstMultiplier_zzX, and helib::ConstMultiplier_DoubleCRT.

7.26.2.2 upgrade()

```
virtual std::shared_ptr<ConstMultiplier> helib::ConstMultiplier::upgrade (
            const Context & context ) const  [pure virtual]
```

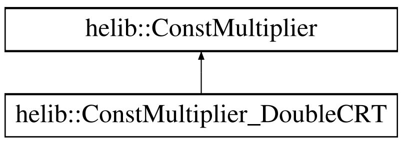
Implemented in helib::ConstMultiplier_zzX.

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

- /HElib/src/matmul.cpp

7.27 helib::ConstMultiplier_DoubleCRT Struct Reference

Inheritance diagram for helib::ConstMultiplier_DoubleCRT:



Public Member Functions

- ConstMultiplier_DoubleCRT (const DoubleCRT &_data, double _sz)
- void mul (Ctxt &ctxt) const override
- std::shared_ptr< ConstMultiplier > upgrade (UNUSED const Context &context) const override

Public Attributes

- DoubleCRT data
- double sz

7.27.1 Constructor & Destructor Documentation

7.27.1.1 ConstMultiplier_DoubleCRT()

```
helib::ConstMultiplier_DoubleCRT::ConstMultiplier_DoubleCRT (
            const DoubleCRT & _data,
            double _sz ) [inline]
```

7.27.2 Member Function Documentation

7.27.2.1 mul()

```
void helib::ConstMultiplier_DoubleCRT::mul (
            Ctxt & ctxt ) const [inline], [override], [virtual]
```

Implements helib::ConstMultiplier.

7.27.2.2 upgrade()

```
std::shared_ptr<ConstMultiplier> helib::ConstMultiplier_DoubleCRT::upgrade (
            UNUSED const Context & context ) const [inline], [override]
```

7.27.3 Member Data Documentation

7.27.3.1 data

```
DoubleCRT helib::ConstMultiplier_DoubleCRT::data
```

7.27.3.2 sz

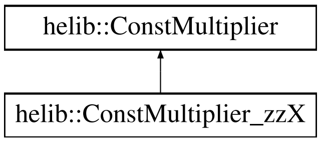
```
double helib::ConstMultiplier_DoubleCRT::sz
```

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

- /HElib/src/matmul.cpp

7.28 helib::ConstMultiplier_zzX Struct Reference

Inheritance diagram for helib::ConstMultiplier_zzX:



Public Member Functions

- ConstMultiplier_zzX (const zzX &_data)
- void mul (Ctxt &ctxt) const override
- std::shared_ptr< ConstMultiplier > upgrade (const Context &context) const override

Public Attributes

- zzX data

7.28.1 Constructor & Destructor Documentation

7.28.1.1 ConstMultiplier_zzX()

```
helib::ConstMultiplier_zzX::ConstMultiplier_zzX (
            const zzX & _data )  [inline]
```

7.28.2 Member Function Documentation

7.28.2.1 mul()

```
void helib::ConstMultiplier_zzX::mul (
            Ctxt & ctxt ) const  [inline], [override], [virtual]
```

Implements helib::ConstMultiplier.

7.28.2.2 upgrade()

```
std::shared_ptr<ConstMultiplier> helib::ConstMultiplier_zzX::upgrade (
            const Context & context ) const  [inline], [override], [virtual]
```

Implements helib::ConstMultiplier.

7.28.3 Member Data Documentation

7.28.3.1 data

```
zzX helib::ConstMultiplier_zzX::data
```

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

- /HElib/src/matmul.cpp

7.29 helib::ConstMultiplierCache Struct Reference

```
#include <matmul.h>
```

Public Member Functions

- void upgrade (const Context &context)

Public Attributes

- std::vector< std::shared_ptr< ConstMultiplier > > multiplier

7.29.1 Member Function Documentation

7.29.1.1 upgrade()

```
void helib::ConstMultiplierCache::upgrade (
            const Context & context )
```

7.29.2 Member Data Documentation

7.29.2.1 multiplier

```
std::vector<std::shared_ptr<ConstMultiplier> > helib::ConstMultiplierCache::multiplier
```

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

- /HElib/include/helib/matmul.h
- /HElib/src/matmul.cpp

7.30 helib::Context Class Reference

Maintaining the parameters.

```
#include <Context.h>
```

Public Member Functions

- double noiseBoundForUniform (double magBound, long degBound) const
- NTL::xdouble noiseBoundForUniform (NTL::xdouble magBound, long degBound) const
- double noiseBoundForMod (long modulus, long degBound) const
- double noiseBoundForGaussian (double sigma, long degBound) const
- double noiseBoundForSmall (double prob, long degBound) const
- double noiseBoundForHWt (long hwt, UNUSED long degBound) const
- double stdDevForRecryption (long skHwt=0) const

  NOTE: this is a bit heuristic. See design document for details.
- double boundForRecryption (long skHwt=0) const
- void setModSizeTable ()
- Context (unsigned long m, unsigned long p, unsigned long r, const std::vector< long > &gens=std::vector< long >(), const std::vector< long > &ords=std::vector< long >())
- void makeBootstrappable (const NTL::Vec< long > &mvec, long skWht=0, bool build_cache=false, bool alsoThick=true)
- bool isBootstrappable () const
- IndexSet fullPrimes () const
- IndexSet allPrimes () const
- IndexSet getCtxtPrimes (long nprimes) const
- long BPL () const
- bool operator== (const Context &other) const
- bool operator!= (const Context &other) const
- long ithPrime (unsigned long i) const

  The ith small prime in the modulus chain.
- const Cmodulus & ithModulus (unsigned long i) const

  Cmodulus object corresponding to ith small prime in the chain.
- long numPrimes () const

  Total number of small prime in the chain.
- bool isZeroDivisor (const NTL::ZZ &num) const

  Is num divisible by any of the primes in the chain?
- bool inChain (long p) const

  Is p already in the chain?
- double logOfPrime (unsigned long i) const

  Returns the natural logarithm of the ith prime.

- double logOfProduct (const IndexSet &s) const

    Returns the natural logarithm of productOfPrimes(s)
- double securityLevel () const

    An estimate for the security-level.
- void AddSmallPrime (long q)

    Just add the given prime to the chain.
- void AddCtxtPrime (long q)
- void AddSpecialPrime (long q)

- void productOfPrimes (NTL::ZZ &p, const IndexSet &s) const

    The product of all the primes in the given set.
- NTL::ZZ productOfPrimes (const IndexSet &s) const

Public Attributes

- PAlgebra zMStar

    The structure of Zm∗.
- PAlgebraMod alMod

    The structure of Z[X]/(Phi_m(X),p^r)
- std::shared_ptr< const EncryptedArray > ea

    A default EncryptedArray.
- std::shared_ptr< const PowerfulDCRT > pwfl_converter
- std::shared_ptr< PolyModRing > slotRing

    The structure of a single slot of the plaintext space.
- NTL::xdouble stdev

    sqrt(variance) of the LWE error (default=3.2)
- double scale
- IndexSet ctxtPrimes
- IndexSet specialPrimes
- IndexSet smallPrimes
- ModuliSizes modSizes

    A helper table to map required modulo-sizes to primeSets.
- std::vector< IndexSet > digits

    The set of primes for the digits.
- ThinRecryptData rcData

    Bootstrapping-related data in the context.

Friends

- void writeContextBinary (std::ostream &str, const Context &context)
- void readContextBinary (std::istream &str, Context &context)

I/O routines

To write out all the data associated with a context, do the following:

```
writeContextBase(str, context);
str « context;
```

The first function call writes out just [m p r gens ords], which is the data needed to invoke the context constructor.

The second call writes out all other information, including the stdev field, the prime sequence (including which primes are "special"), and the digits info.

To read in all the data associated with a context, do the following:

```
unsigned long m, p, r;
std::vector<long> gens, ords;
readContextBase(str, m, p, r, gens, ords);
Context context(m, p, r, gens, ords);
str » context;
```

The call to readContextBase just reads the values m, p, r and the set of generators in Zm∗ /(p) and their order. Then, after constructing the context, the >> operator reads in and attaches all other information.

- void writeContextBase (std::ostream &str, const Context &context)
  write [m p r] data
- std::ostream & operator<< (std::ostream &str, const Context &context)
  Write all other data.
- void readContextBase (std::istream &str, unsigned long &m, unsigned long &p, unsigned long &r, std::vector< long > &gens, std::vector< long > &ords)
  read [m p r] data, needed to construct context
- std::istream & operator>> (std::istream &str, Context &context)
  read all other data associated with context

7.30.1 Detailed Description

Maintaining the parameters.

7.30.2 Constructor & Destructor Documentation

7.30.2.1 Context()

```
helib::Context::Context (
            unsigned long m,
            unsigned long p,
            unsigned long r,
            const std::vector< long > & gens = std::vector<long>(),
            const std::vector< long > & ords = std::vector<long>() )
```

7.30.3 Member Function Documentation

7.30.3.1 AddCtxtPrime()

```
void helib::Context::AddCtxtPrime (
            long q )
```

7.30.3.2 AddSmallPrime()

```
void helib::Context::AddSmallPrime (
            long q )
```

Just add the given prime to the chain.

7.30.3.3 AddSpecialPrime()

```
void helib::Context::AddSpecialPrime (
            long q )
```

7.30.3.4 allPrimes()

```
IndexSet helib::Context::allPrimes ( ) const [inline]
```

7.30.3.5 boundForRecryption()

```
double helib::Context::boundForRecryption (
            long skHwt = 0 ) const [inline]
```

7.30.3.6 BPL()

```
long helib::Context::BPL ( ) const [inline]
```

7.30.3.7 fullPrimes()

```
IndexSet helib::Context::fullPrimes ( ) const [inline]
```

7.30.3.8 getCtxtPrimes()

```
IndexSet helib::Context::getCtxtPrimes (
            long nprimes ) const [inline]
```

7.30.3.9 inChain()

```
bool helib::Context::inChain (
             long p ) const  [inline]
```

Is p already in the chain?

7.30.3.10 isBootstrappable()

```
bool helib::Context::isBootstrappable ( ) const  [inline]
```

7.30.3.11 isZeroDivisor()

```
bool helib::Context::isZeroDivisor (
             const NTL::ZZ & num ) const  [inline]
```

Is num divisible by any of the primes in the chain?

7.30.3.12 ithModulus()

```
const Cmodulus& helib::Context::ithModulus (
             unsigned long i ) const  [inline]
```

Cmodulus object corresponding to ith small prime in the chain.

7.30.3.13 ithPrime()

```
long helib::Context::ithPrime (
             unsigned long i ) const  [inline]
```

The ith small prime in the modulus chain.

7.30.3.14 logOfPrime()

```
double helib::Context::logOfPrime (
             unsigned long i ) const  [inline]
```

Returns the natural logarithm of the ith prime.

7.30.3.15 logOfProduct()

```
double helib::Context::logOfProduct (
            const IndexSet & s ) const [inline]
```

Returns the natural logarithm of productOfPrimes(s)

7.30.3.16 makeBootstrappable()

```
void helib::Context::makeBootstrappable (
            const NTL::Vec< long > & mvec,
            long skWht = 0,
            bool build_cache = false,
            bool alsoThick = true ) [inline]
```

7.30.3.17 noiseBoundForGaussian()

```
double helib::Context::noiseBoundForGaussian (
            double sigma,
            long degBound ) const [inline]
```

Assume the polynomial f(x) = sum_{i < k} f_i x^i is chosen so that each f_i is chosen uniformly and independently from N(0, sigma^2), and that k = degBound. This returns a bound B such that the L-infty norm of the canonical embedding exceeds B with probability at most epsilon.

7.30.3.18 noiseBoundForHWt()

```
double helib::Context::noiseBoundForHWt (
            long hwt,
            UNUSED long degBound ) const [inline]
```

Assume the polynomial f(x) = sum_{i < k} f_i x^i is chosen hwt coefficients are chosen to \pm 1, and the remainder zero. This returns a bound B such that the L-infty norm of the canonical embedding exceeds B with probability at most epsilon.

7.30.3.19 noiseBoundForMod()

```
double helib::Context::noiseBoundForMod (
            long modulus,
            long degBound ) const [inline]
```

Assume the polynomial f(x) = sum_{i < k} f_i x^i is chosen so that each f_i is chosen uniformly and independently from the from the set of balanced residues modulo the given modulus. This returns a bound B such that the L-infty norm of the canonical embedding exceeds B with probability at most epsilon.

7.30.3.20 noiseBoundForSmall()

```
double helib::Context::noiseBoundForSmall (
            double prob,
            long degBound ) const  [inline]
```

Assume the polynomial f(x) = sum_{i < k} f_i x^i is chosen so that each f_i is zero with probability 1-prob, 1 with probability prob/2, and -1 with probability prob/2. This returns a bound B such that the L-infty norm of the canonical embedding exceeds B with probability at most epsilon.

7.30.3.21 noiseBoundForUniform() [1/2]

```
double helib::Context::noiseBoundForUniform (
            double magBound,
            long degBound ) const  [inline]
```

erfc(scale/sqrt(2)) * phi(m) should be less than some negligible parameter epsilon. The default value of 10 should be good enough for most applications. NOTE: -log(erfc(8/sqrt(2)))/log(2) = 49.5 -log(erfc(10/sqrt(2)))/log(2) = 75.8 -log(erfc(11/sqrt(2)))/log(2) = 91.1 -log(erfc(12/sqrt(2)))/log(2) =107.8 The way this is used is as follows. If we have a normal random variable X with variance sigma^2, then the probability that that X lies outside the interval [-scale*sigma, scale*sigma] is delta=erfc(scale/sqrt(2)). We will usually apply the union bound to a vector of phi(m) such random variables (one for each primitive m-th root of unity), so that the probability that that the L-infty norm exceeds scale*sigma is at most epsilon=phim*delta. Thus, scale*sigma will be used as a high-probability bound on the L-infty norm of such vectors. Assume the polynomial f(x) = sum_{i < k} f_i x^i is chosen so that each f_i is chosen uniformly and independently from the interval [-magBound, magBound], and that k = degBound. This returns a bound B such that the L-infty norm of the canonical embedding exceeds B with probability at most epsilon.

7.30.3.22 noiseBoundForUniform() [2/2]

```
NTL::xdouble helib::Context::noiseBoundForUniform (
            NTL::xdouble magBound,
            long degBound ) const  [inline]
```

7.30.3.23 numPrimes()

```
long helib::Context::numPrimes ( ) const  [inline]
```

Total number of small prime in the chain.

7.30.3.24 operator"!=()

```
bool helib::Context::operator!= (
            const Context & other ) const  [inline]
```

7.30.3.25 operator==()

```
bool helib::Context::operator== (
            const Context & other ) const
```

7.30.3.26 productOfPrimes() [1/2]

```
NTL::ZZ helib::Context::productOfPrimes (
            const IndexSet & s ) const [inline]
```

7.30.3.27 productOfPrimes() [2/2]

```
void helib::Context::productOfPrimes (
            NTL::ZZ & p,
            const IndexSet & s ) const
```

The product of all the primes in the given set.

7.30.3.28 securityLevel()

```
double helib::Context::securityLevel ( ) const [inline]
```

An estimate for the security-level.

7.30.3.29 setModSizeTable()

```
void helib::Context::setModSizeTable ( ) [inline]
```

7.30.3.30 stdDevForRecryption()

```
double helib::Context::stdDevForRecryption (
            long skHwt = 0 ) const [inline]
```

NOTE: this is a bit heuristic. See design document for details.

This computes a high probability bound on the L-infty norm of x0+s∗x1 in the pwrfl basis, assuming is chosen with coeffs in the pwrfl basis uniformly and independently dist'd over [-1/2,1/2], x0 has arbitrary coeffs over [-1/2,1/2] in the pwrfl basis, and assuming s is chosen with skHwt nonzero coeffs mod X^m-1 in the power basis (uniformly and independently over {-1,1}). The bound should be satisfied with probability epsilon. NOTE: this is still valid even when m is a power of 2

7.30.4 Friends And Related Function Documentation

7.30.4.1 operator<<

```
std::ostream& operator<< (
            std::ostream & str,
            const Context & context )  [friend]
```

Write all other data.

7.30.4.2 operator>>

```
std::istream& operator>> (
            std::istream & str,
            Context & context )  [friend]
```

read all other data associated with context

7.30.4.3 readContextBase

```
void readContextBase (
            std::istream & str,
            unsigned long & m,
            unsigned long & p,
            unsigned long & r,
            std::vector< long > & gens,
            std::vector< long > & ords )  [friend]
```

read [m p r] data, needed to construct context

7.30.4.4 readContextBinary

```
void readContextBinary (
            std::istream & str,
            Context & context )  [friend]
```

7.30.4.5 writeContextBase

```
void writeContextBase (
            std::ostream & str,
            const Context & context )  [friend]
```

write [m p r] data

7.30.4.6 writeContextBinary

```
void writeContextBinary (
            std::ostream & str,
            const Context & context )  [friend]
```

7.30.5 Member Data Documentation

7.30.5.1 alMod

```
PAlgebraMod helib::Context::alMod
```

The structure of Z[X]/(Phi_m(X),p^r)

7.30.5.2 ctxtPrimes

```
IndexSet helib::Context::ctxtPrimes
```

The "ciphertext primes" are the "normal" primes that are used to represent the public encryption key and ciphertexts. These are all "large" single=precision primes, or bit-size roughly NTL_SP_SIZE bits.

7.30.5.3 digits

```
std::vector<IndexSet> helib::Context::digits
```

The set of primes for the digits.

The different columns in any key-switching matrix contain encryptions of multiplies of the secret key, sk, B1∗sk, B2∗B1∗sk, B3∗B2∗B1∗sk,... with each Bi a product of a few "non-special" primes in the chain. The digits data member indicate which primes correspond to each of the Bi's. These are all IndexSet objects, whose union is the subset ctxtPrimes.

The number of Bi's is one less than the number of columns in the key switching matrices (since the 1st column encrypts sk, without any Bi's), but we keep in the digits std::vector also an entry for the primes that do not participate in any Bi (so digits.size() is the same as the number of columns in the key switching matrices). See section 3.1.6 in the design document (key-switching).

7.30.5.4 ea

```
std::shared_ptr<const EncryptedArray> helib::Context::ea
```

A default EncryptedArray.

7.30.5.5 modSizes

```
ModuliSizes helib::Context::modSizes
```

A helper table to map required modulo-sizes to primeSets.

7.30.5.6 pwfl_converter

```
std::shared_ptr<const PowerfulDCRT> helib::Context::pwfl_converter
```

7.30.5.7 rcData

```
ThinRecryptData helib::Context::rcData
```

Bootstrapping-related data in the context.

7.30.5.8 scale

```
double helib::Context::scale
```

7.30.5.9 slotRing

```
std::shared_ptr<PolyModRing> helib::Context::slotRing
```

The structure of a single slot of the plaintext space.

This will be Z[X]/(G(x),p^r) for some irreducible factor G of Phi_m(X).

7.30.5.10 smallPrimes

```
IndexSet helib::Context::smallPrimes
```

Yet a third set of primes, aimed at allowing modulus-switching with higher resolution. These are somewhat smaller single-precision primes, of size from NTL_SP_SIZE-20 to NTL_SP_SIZE-1.

7.30.5.11 specialPrimes

```
IndexSet helib::Context::specialPrimes
```

A disjoint set of primes, used for key switching. See section 3.1.6 in the design document (key-switching). These too are "large" single=precision primes, or bit-size close to NTL_SP_SIZE bits.

7.30.5.12 stdev

```
NTL::xdouble helib::Context::stdev
```

sqrt(variance) of the LWE error (default=3.2)

7.30.5.13 zMStar

```
PAlgebra helib::Context::zMStar
```

The structure of Zm$*$.

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

- /HElib/include/helib/Context.h
- /HElib/src/Context.cpp
- /HElib/src/primeChain.cpp

7.31 helib::Ctxt Class Reference

A Ctxt object holds a single ciphertext.

```
#include <Ctxt.h>
```

Public Member Functions

- Ctxt (const PubKey &newPubKey, long newPtxtSpace=0)
- Ctxt (const Ctxt &other)=default
- Ctxt (ZeroCtxtLike_type, const Ctxt &ctxt)
- void DummyEncrypt (const NTL::ZZX &ptxt, double size=-1.0)
- Ctxt & operator= (const Ctxt &other)
- bool operator== (const Ctxt &other) const
- bool operator!= (const Ctxt &other) const
- bool equalsTo (const Ctxt &other, bool comparePkeys=true) const
- void write (std::ostream &str) const
- void read (std::istream &str)

Ciphertext arithmetic

- void negate ()
- Ctxt & operator+= (const Ctxt &other)
- Ctxt & operator-= (const Ctxt &other)
- void addCtxt (const Ctxt &other, bool negative=false)
- void multLowLvl (const Ctxt &other, bool destructive=false)
- Ctxt & operator*= (const Ctxt &other)
- void automorph (long k)
- Ctxt & operator>>= (long k)
- void complexConj ()
- void smartAutomorph (long k)

  automorphism with re-linearization
- void frobeniusAutomorph (long j)

  applies the automorphism p^j using smartAutomorphism
- Ctxt & operator+= (const Ptxt< BGV > &other)

  Plus equals operator with a `BGV` `Ptxt`.
- Ctxt & operator-= (const Ptxt< BGV > &other)

  Minus equals operator with a `BGV` `Ptxt`.
- Ctxt & operator*= (const Ptxt< BGV > &other)

  Times equals operator with a `BGV` `Ptxt`.
- Ctxt & operator+= (const Ptxt< CKKS > &other)

  Plus equals operator with a `CKKS` `Ptxt`.
- Ctxt & operator-= (const Ptxt< CKKS > &other)

  Minus equals operator with a `CKKS` `Ptxt`.
- Ctxt & operator*= (const Ptxt< CKKS > &other)

  Times equals operator with a `CKKS` `Ptxt`.
- Ctxt & operator*= (const NTL::ZZX &poly)

  Times equals operator with a `ZZX`.
- Ctxt & operator*= (const long scalar)

  Times equals operator with a `long`.
- void addConstant (const DoubleCRT &dcrt, double size=-1.0)
- void addConstant (const NTL::ZZX &poly, double size=-1.0)
- template<typename Scheme >
  void addConstant (const Ptxt< Scheme > &ptxt)

  Add a `BGV` plaintext to this `Ctxt`.
- void addConstant (const NTL::ZZ &c)
- void addConstantCKKS (std::pair< long, long >)

  add a rational number in the form a/b, a,b are long
- void addConstantCKKS (double x)
- void addConstantCKKS (const DoubleCRT &dcrt, NTL::xdouble size=NTL::xdouble(-1.0), NTL::xdouble factor=NTL::xdouble(-1.0))
- void addConstantCKKS (const NTL::ZZX &poly, NTL::xdouble size=NTL::xdouble(-1.0), NTL::xdouble factor=NTL::xdouble(-1.0))
- void addConstantCKKS (const std::vector< std::complex< double >> &ptxt)
- void addConstantCKKS (const Ptxt< CKKS > &ptxt)

Add a `CKKS` plaintext to this `Ctxt`.

- void addConstantCKKS (const NTL::ZZ &c)
- void multByConstant (const DoubleCRT &dcrt, double size=-1.0)
- void multByConstant (const NTL::ZZX &poly, double size=-1.0)
- void multByConstant (const zzX &poly, double size=-1.0)
- void multByConstant (const NTL::ZZ &c)
- template< typename Scheme >
  void multByConstant (const Ptxt< Scheme > &ptxt)

  Multiply a `BGV` plaintext to this `Ctxt`.
- void multByConstantCKKS (double x)

  multiply by a rational number or floating point
- void multByConstantCKKS (std::pair< long, long > num)
- void multByConstantCKKS (const DoubleCRT &dcrt, NTL::xdouble size=NTL::xdouble(-1.0), NTL::xdouble factor=NTL::xdouble(-1.0), double roundingErr=-1.0)
- void multByConstantCKKS (const NTL::ZZX &poly, NTL::xdouble size=NTL::xdouble(-1.0), NTL::xdouble factor=NTL::xdouble(-1.0), double roundingErr=-1.0)
- void multByConstantCKKS (const Ptxt< CKKS > &ptxt)

  Multiply a `CKKS` plaintext to this `Ctxt`.
- void multByConstantCKKS (const std::vector< std::complex< double >> &ptxt)
- void xorConstant (const DoubleCRT &poly, UNUSED double size=-1.0)
- void xorConstant (const NTL::ZZX &poly, double size=-1.0)
- void nxorConstant (const DoubleCRT &poly, UNUSED double size=-1.0)
- void nxorConstant (const NTL::ZZX &poly, double size=-1.0)
- void divideByP ()
- void multByP (long e=1)
- void divideBy2 ()
- void extractBits (std::vector< Ctxt > &bits, long nBits2extract=0)
- void multiplyBy (const Ctxt &other)
- void multiplyBy2 (const Ctxt &other1, const Ctxt &other2)
- void square ()
- void cube ()
- void power (long e)

  raise ciphertext to some power

Ciphertext maintenance

- void reducePtxtSpace (long newPtxtSpace)

  Reduce plaintext space to a divisor of the original plaintext space.
- void hackPtxtSpace (long newPtxtSpace)
- void bumpNoiseBound (double factor)
- void reLinearize (long keyIdx=0)
- void cleanUp ()
- void blindCtxt (const NTL::ZZX &poly)

  Add a high-noise encryption of the given constant.
- NTL::xdouble modSwitchAddedNoiseBound () const

  Estimate the added noise.
- void modUpToSet (const IndexSet &s)

  Modulus-switching up (to a larger modulus). Must have primeSet <= s, and s must contain either all the special primes or none of them.
- void modDownToSet (const IndexSet &s)

  Modulus-switching down (to a smaller modulus). mod-switch down to primeSet \intersect s, after this call we have primeSet<=s. s must contain either all special primes or none of them.
- void bringToSet (const IndexSet &s)

  make the primeSet equal to newPrimeSet, via modUpToSet and modDownToSet
- double naturalSize () const
- IndexSet naturalPrimeSet () const

  "natural size" is size before squaring
- void dropSmallAndSpecialPrimes ()

  the corresponding primeSet
- double capacity () const

  returns the "capacity" of a ciphertext, which is the log of the ratio of the modulus to the noise bound

- long bitCapacity () const
  the capacity in bits, returned as an integer
- double logOfPrimeSet () const
  returns the log of the prime set
- double rawModSwitch (std::vector< NTL::ZZX > &zzParts, long toModulus) const
  Special-purpose modulus-switching for bootstrapping.
- void evalPoly (const NTL::ZZX &poly)
  compute the power X,X^2,...,X^n

Utility methods

- void clear ()
- bool isEmpty () const
  Is this an empty ciphertext without any parts.
- bool inCanonicalForm (long keyID=0) const
  A canonical ciphertext has (at most) handles pointing to (1,s)
- bool isCorrect () const
  Would this ciphertext be decrypted without errors?
- const Context & getContext () const
- const PubKey & getPubKey () const
- const IndexSet & getPrimeSet () const
- long getPtxtSpace () const
- const NTL::xdouble & getNoiseBound () const
- const NTL::xdouble & getRatFactor () const
- const NTL::xdouble & getPtxtMag () const
- void setPtxtMag (const NTL::xdouble &z)
- long getKeyID () const
- bool isCKKS () const
- long effectiveR () const
- double log_of_ratio () const
  Returns log(noiseBound) - log(q)

Static Public Member Functions

- static void equalizeRationalFactors (Ctxt &c1, Ctxt &c2)

Friends

- class PubKey
- class SecKey
- class BasicAutomorphPrecon
- std::istream & operator>> (std::istream &str, Ctxt &ctxt)
- std::ostream & operator<< (std::ostream &str, const Ctxt &ctxt)

7.31.1 Detailed Description

A Ctxt object holds a single ciphertext.

The class Ctxt includes a std::vector<CtxtPart>: For a Ctxt c, c[i] is the i'th ciphertext part, which can be used also as a DoubleCRT object (since CtxtPart is derived from DoubleCRT). By convention, c[0], the first CtxtPart object in the std::vector, has skHndl that points to 1 (i.e., it is just added in upon decryption, without being multiplied by anything). We maintain the invariance that all the parts of a ciphertext are defined relative to the same set of primes.

A ciphertext contains also pointers to the general parameters of this FHE instance and the public key, and a high-probability bound on the noise magnitude (kept in the noiseBound data member). The noise bound is a bound on the l-infinity norm of the canonical embedding of the noise polynomial, namely its evaluation in roots of the ring polynomial (which are the complex primitive roots of unity). The noise bound is added on addition, multiplied on multiplications, remains unchanged for automorphism, and is roughly scaled down by mod-switching with some added factor, and similarly scaled up by key-switching with some added factor.

7.31.2 Constructor & Destructor Documentation

7.31.2.1 Ctxt() [1/3]

```
helib::Ctxt::Ctxt (
            const PubKey & newPubKey,
            long newPtxtSpace = 0 )  [explicit]
```

7.31.2.2 Ctxt() [2/3]

```
helib::Ctxt::Ctxt (
            const Ctxt & other )  [default]
```

7.31.2.3 Ctxt() [3/3]

```
helib::Ctxt::Ctxt (
            ZeroCtxtLike_type ,
            const Ctxt & ctxt )
```

7.31.3 Member Function Documentation

7.31.3.1 addConstant() [1/4]

```
void helib::Ctxt::addConstant (
            const DoubleCRT & dcrt,
            double size = -1.0 )
```

Add a constant polynomial. If provided, size should be a high-probability bound on the L-infty norm of the canonical embedding Otherwise, for the DoubleCRT variant, a bound based on the assumption that the coefficients are uniformly and independently distributed over [-ptxtSpace/2, ptxtSpace/2]. For the other variants, explicit bounds are computed (if not CKKS).

7.31.3.2 addConstant() [2/4]

```
void helib::Ctxt::addConstant (
            const NTL::ZZ & c )
```

7.31.3.3 addConstant() [3/4]

```
void helib::Ctxt::addConstant (
            const NTL::ZZX & poly,
            double size = -1.0 )
```

7.31.3.4 addConstant() [4/4]

```
template<typename Scheme >
void helib::Ctxt::addConstant (
            const Ptxt< Scheme > & ptxt )   [inline]
```

Add a BGV plaintext to this Ctxt.

Parameters

ptxt	Plaintext Ptxt object with which to add.

7.31.3.5 addConstantCKKS() [1/7]

```
void helib::Ctxt::addConstantCKKS (
            const DoubleCRT & dcrt,
            NTL::xdouble size = NTL::xdouble(-1.0),
            NTL::xdouble factor = NTL::xdouble(-1.0) )
```

7.31.3.6 addConstantCKKS() [2/7]

```
void helib::Ctxt::addConstantCKKS (
            const NTL::ZZ & c )
```

7.31.3.7 addConstantCKKS() [3/7]

```
void helib::Ctxt::addConstantCKKS (
            const NTL::ZZX & poly,
            NTL::xdouble size = NTL::xdouble(-1.0),
            NTL::xdouble factor = NTL::xdouble(-1.0) )
```

7.31.3.8 addConstantCKKS() [4/7]

```
void helib::Ctxt::addConstantCKKS (
            const Ptxt< CKKS > & ptxt )
```

Add a CKKS plaintext to this Ctxt.

Parameters

ptxt	Plaintext Ptxt object with which to add.

7.31.3.9 addConstantCKKS() [5/7]

```
void helib::Ctxt::addConstantCKKS (
            const std::vector< std::complex< double >> & ptxt )
```

7.31.3.10 addConstantCKKS() [6/7]

```
void helib::Ctxt::addConstantCKKS (
            double x ) [inline]
```

7.31.3.11 addConstantCKKS() [7/7]

```
void helib::Ctxt::addConstantCKKS (
            std::pair< long, long > num )
```

add a rational number in the form a/b, a,b are long

7.31.3.12 addCtxt()

```
void helib::Ctxt::addCtxt (
            const Ctxt & other,
            bool negative = false )
```

7.31.3.13 automorph()

```
void helib::Ctxt::automorph (
            long k )
```

7.31.3.14 bitCapacity()

```
long helib::Ctxt::bitCapacity ( ) const  [inline]
```

the capacity in bits, returned as an integer

7.31.3.15 blindCtxt()

```
void helib::Ctxt::blindCtxt (
            const NTL::ZZX & poly )
```

Add a high-noise encryption of the given constant.

7.31.3.16 bringToSet()

```
void helib::Ctxt::bringToSet (
            const IndexSet & s )
```

make the primeSet equal to newPrimeSet, via modUpToSet and modDownToSet

7.31.3.17 bumpNoiseBound()

```
void helib::Ctxt::bumpNoiseBound (
            double factor )  [inline]
```

7.31.3.18 capacity()

```
double helib::Ctxt::capacity ( ) const  [inline]
```

returns the "capacity" of a ciphertext, which is the log of the ratio of the modulus to the noise bound

7.31.3.19 cleanUp()

```
void helib::Ctxt::cleanUp ( )
```

7.31.3.20 clear()

```
void helib::Ctxt::clear ( ) [inline]
```

7.31.3.21 complexConj()

```
void helib::Ctxt::complexConj ( )
```

7.31.3.22 cube()

```
void helib::Ctxt::cube ( ) [inline]
```

7.31.3.23 divideBy2()

```
void helib::Ctxt::divideBy2 ( )
```

7.31.3.24 divideByP()

```
void helib::Ctxt::divideByP ( )
```

Divide a ciphertext by p, for plaintext space p^r, r>1. It is assumed that the ciphertext encrypts a polynomial which is zero mod p. If this is not the case then the result will not be a valid ciphertext anymore. As a side-effect, the plaintext space is reduced from p^r to p^{r-1}.

7.31.3.25 dropSmallAndSpecialPrimes()

```
void helib::Ctxt::dropSmallAndSpecialPrimes ( )
```

the corresponding primeSet

drop all smallPrimes and specialPrimes, adding ctxtPrimes as necessary to ensure that the scaled noise is above the modulus-switching added noise term.

7.31.3.26 DummyEncrypt()

```
void helib::Ctxt::DummyEncrypt (
            const NTL::ZZX & ptxt,
            double size = -1.0 )
```

Dummy encryption, just encodes the plaintext in a Ctxt object If provided, size should be a high-probability bound on the L-infty norm of the canonical embedding

7.31.3.27 effectiveR()

```
long helib::Ctxt::effectiveR ( ) const  [inline]
```

7.31.3.28 equalizeRationalFactors()

```
void helib::Ctxt::equalizeRationalFactors (
            Ctxt & c1,
            Ctxt & c2 )  [static]
```

7.31.3.29 equalsTo()

```
bool helib::Ctxt::equalsTo (
            const Ctxt & other,
            bool comparePkeys = true ) const
```

7.31.3.30 evalPoly()

```
void helib::Ctxt::evalPoly (
            const NTL::ZZX & poly )
```

compute the power X,X^2,...,X^n

Evaluate the cleartext poly on the encrypted ciphertext

7.31.3.31 extractBits()

```
void helib::Ctxt::extractBits (
            std::vector< Ctxt > & bits,
            long nBits2extract = 0 )  [inline]
```

7.31.3.32 frobeniusAutomorph()

```
void helib::Ctxt::frobeniusAutomorph (
            long j )
```

applies the automorphism p^j using smartAutomorphism

7.31.3.33 getContext()

```
const Context& helib::Ctxt::getContext ( ) const [inline]
```

7.31.3.34 getKeyID()

```
long helib::Ctxt::getKeyID ( ) const
```

7.31.3.35 getNoiseBound()

```
const NTL::xdouble& helib::Ctxt::getNoiseBound ( ) const [inline]
```

7.31.3.36 getPrimeSet()

```
const IndexSet& helib::Ctxt::getPrimeSet ( ) const [inline]
```

7.31.3.37 getPtxtMag()

```
const NTL::xdouble& helib::Ctxt::getPtxtMag ( ) const [inline]
```

7.31.3.38 getPtxtSpace()

```
long helib::Ctxt::getPtxtSpace ( ) const [inline]
```

7.31.3.39 getPubKey()

```
const PubKey& helib::Ctxt::getPubKey ( ) const [inline]
```

7.31.3.40 getRatFactor()

```
const NTL::xdouble& helib::Ctxt::getRatFactor ( ) const [inline]
```

7.31.3.41 hackPtxtSpace()

```
void helib::Ctxt::hackPtxtSpace (
            long newPtxtSpace ) [inline]
```

7.31.3.42 inCanonicalForm()

```
bool helib::Ctxt::inCanonicalForm (
            long keyID = 0 ) const [inline]
```

A canonical ciphertext has (at most) handles pointing to (1,s)

7.31.3.43 isCKKS()

```
bool helib::Ctxt::isCKKS ( ) const [inline]
```

7.31.3.44 isCorrect()

```
bool helib::Ctxt::isCorrect ( ) const [inline]
```

Would this ciphertext be decrypted without errors?

7.31.3.45 isEmpty()

```
bool helib::Ctxt::isEmpty ( ) const [inline]
```

Is this an empty ciphertext without any parts.

7.31.3.46 log_of_ratio()

```
double helib::Ctxt::log_of_ratio ( ) const [inline]
```

Returns log(noiseBound) - log(q)

7.31.3.47 logOfPrimeSet()

```
double helib::Ctxt::logOfPrimeSet ( ) const [inline]
```

returns the log of the prime set

7.31.3.48 modDownToSet()

```
void helib::Ctxt::modDownToSet (
            const IndexSet & s )
```

Modulus-switching down (to a smaller modulus). mod-switch down to primeSet \intersect s, after this call we have primeSet<=s. s must contain either all special primes or none of them.

7.31.3.49 modSwitchAddedNoiseBound()

```
NTL::xdouble helib::Ctxt::modSwitchAddedNoiseBound ( ) const
```

Estimate the added noise.

7.31.3.50 modUpToSet()

```
void helib::Ctxt::modUpToSet (
            const IndexSet & s )
```

Modulus-switching up (to a larger modulus). Must have primeSet <= s, and s must contain either all the special primes or none of them.

7.31.3.51 multByConstant() [1/5]

```
void helib::Ctxt::multByConstant (
            const DoubleCRT & dcrt,
            double size = -1.0 )
```

Multiply-by-constant. If the size is not given, for the DCRT variant, we use a high probability bound assuming "random" coefficients mod ptxtSpace, while for the other variants, we use explicitly computed bounds (if not CKKS).

7.31.3.52 multByConstant() [2/5]

```
void helib::Ctxt::multByConstant (
            const NTL::ZZ & c )
```

7.31.3.53 multByConstant() [3/5]

```
void helib::Ctxt::multByConstant (
            const NTL::ZZX & poly,
            double size = -1.0 )
```

7.31.3.54 multByConstant() [4/5]

```
template<typename Scheme >
void helib::Ctxt::multByConstant (
            const Ptxt< Scheme > & ptxt )  [inline]
```

Multiply a BGV plaintext to this Ctxt.

Parameters

ptxt	Plaintext Ptxt object with which to multiply.

7.31.3.55 multByConstant() [5/5]

```
void helib::Ctxt::multByConstant (
            const zzX & poly,
            double size = -1.0 )
```

7.31.3.56 multByConstantCKKS() [1/6]

```
void helib::Ctxt::multByConstantCKKS (
            const DoubleCRT & dcrt,
            NTL::xdouble size = NTL::xdouble(-1.0),
            NTL::xdouble factor = NTL::xdouble(-1.0),
            double roundingErr = -1.0 )
```

7.31.3.57 multByConstantCKKS() [2/6]

```
void helib::Ctxt::multByConstantCKKS (
            const NTL::ZZX & poly,
            NTL::xdouble size = NTL::xdouble(-1.0),
            NTL::xdouble factor = NTL::xdouble(-1.0),
            double roundingErr = -1.0 )  [inline]
```

7.31.3.58 multByConstantCKKS() [3/6]

```
void helib::Ctxt::multByConstantCKKS (
            const Ptxt< CKKS > & ptxt )
```

Multiply a CKKS plaintext to this Ctxt.

Parameters

ptxt	Plaintext Ptxt object polynomial with which to multiply.

7.31.3.59 multByConstantCKKS() [4/6]

```
void helib::Ctxt::multByConstantCKKS (
            const std::vector< std::complex< double >> & ptxt )
```

7.31.3.60 multByConstantCKKS() [5/6]

```
void helib::Ctxt::multByConstantCKKS (
            double x )  [inline]
```

multiply by a rational number or floating point

7.31.3.61 multByConstantCKKS() [6/6]

```
void helib::Ctxt::multByConstantCKKS (
            std::pair< long, long > num )  [inline]
```

7.31.3.62 multByP()

```
void helib::Ctxt::multByP (
            long e = 1 )  [inline]
```

Multiply ciphertext by p^e, for plaintext space p^r. This also has the side-effect of increasing the plaintext space to p^{r+e}.

7.31.3.63 multiplyBy()

```
void helib::Ctxt::multiplyBy (
            const Ctxt & other )
```

7.31.3.64 multiplyBy2()

```
void helib::Ctxt::multiplyBy2 (
            const Ctxt & other1,
            const Ctxt & other2 )
```

7.31.3.65 multLowLvl()

```
void helib::Ctxt::multLowLvl (
            const Ctxt & other,
            bool destructive = false )
```

7.31.3.66 naturalPrimeSet()

```
IndexSet helib::Ctxt::naturalPrimeSet ( ) const
```

"natural size" is size before squaring

7.31.3.67 naturalSize()

```
double helib::Ctxt::naturalSize ( ) const
```

7.31.3.68 negate()

```
void helib::Ctxt::negate ( )
```

7.31.3.69 nxorConstant() [1/2]

```
void helib::Ctxt::nxorConstant (
            const DoubleCRT & poly,
            UNUSED double size = -1.0 )  [inline]
```

7.31.3.70 nxorConstant() [2/2]

```
void helib::Ctxt::nxorConstant (
            const NTL::ZZX & poly,
            double size = -1.0 )  [inline]
```

7.31.3.71 operator"!=()

```
bool helib::Ctxt::operator!= (
            const Ctxt & other ) const  [inline]
```

7.31.3.72 operator*=() [1/5]

```
Ctxt& helib::Ctxt::operator*= (
            const Ctxt & other )  [inline]
```

7.31.3.73 operator*=() [2/5]

```
Ctxt & helib::Ctxt::operator*= (
            const long scalar )
```

Times equals operator with a `long`.

Parameters

scalar	Constant by which to multiply.

Returns

Reference to `*this` post multiplication.

7.31.3.74 operator*=() [3/5]

```
Ctxt & helib::Ctxt::operator*= (
            const NTL::ZZX & poly )
```

Times equals operator with a `ZZX`.

Parameters

poly	Element by which to multiply.

Returns

Reference to `*this` post multiplication.

7.31.3.75 operator*=() [4/5]

```
Ctxt & helib::Ctxt::operator*= (
            const Ptxt< BGV > & other )
```

Times equals operator with a BGV `Ptxt`.

Parameters

other	Right hand side of multiplication.

Returns

reference to `*this` post multiplication.

7.31.3.76 operator*=() [5/5]

```
Ctxt & helib::Ctxt::operator*= (
            const Ptxt< CKKS > & other )
```

Times equals operator with a CKKS `Ptxt`.

Parameters

other	Right hand side of multiplication.

Returns

Reference to `*this` post multiplication.

7.31.3.77 operator+=() [1/3]

```
Ctxt& helib::Ctxt::operator+= (
            const Ctxt & other ) [inline]
```

7.31.3.78 operator+=() [2/3]

```
Ctxt & helib::Ctxt::operator+= (
            const Ptxt< BGV > & other )
```

Plus equals operator with a BGV `Ptxt`.

Parameters

other	Right hand side of addition.

Returns

Reference to `*this` post addition.

7.31.3.79 operator+=() [3/3]

```
Ctxt & helib::Ctxt::operator+= (
            const Ptxt< CKKS > & other )
```

Plus equals operator with a CKKS Ptxt.

Parameters

other	Right hand side of addition.

Returns

Reference to `*this` post addition.

7.31.3.80 operator-=() [1/3]

```
Ctxt& helib::Ctxt::operator-= (
            const Ctxt & other )  [inline]
```

7.31.3.81 operator-=() [2/3]

```
Ctxt & helib::Ctxt::operator-= (
            const Ptxt< BGV > & other )
```

Minus equals operator with a BGV Ptxt.

Parameters

other	Right hand side of subtraction.

Returns

Reference to `*this` post subtraction.

7.31.3.82 operator-=() [3/3]

```
Ctxt & helib::Ctxt::operator-= (
            const Ptxt< CKKS > & other )
```

Minus equals operator with a `CKKS Ptxt`.

Parameters

other	Right hand side of subtraction.

Returns

Reference to `*this` post subtraction.

7.31.3.83 operator=()

```
Ctxt& helib::Ctxt::operator= (
            const Ctxt & other ) [inline]
```

7.31.3.84 operator==()

```
bool helib::Ctxt::operator== (
            const Ctxt & other ) const [inline]
```

7.31.3.85 operator>>=()

```
Ctxt& helib::Ctxt::operator>>= (
            long k ) [inline]
```

7.31.3.86 power()

```
void helib::Ctxt::power (
            long e )
```

raise ciphertext to some power

7.31.3.87 rawModSwitch()

```
double helib::Ctxt::rawModSwitch (
            std::vector< NTL::ZZX > & zzParts,
            long toModulus ) const
```

Special-purpose modulus-switching for bootstrapping.

Mod-switch to an externally-supplied modulus. The modulus need not be in the moduli-chain in the context, and does not even need to be a prime. The ciphertext ∗this is not affected, instead the result is returned in the zzParts std::vector, as a std::vector of ZZX'es. Returns an estimate for the scaled noise (not including the additive mod switching noise)

7.31.3.88 read()

```
void helib::Ctxt::read (
            std::istream & str )
```

7.31.3.89 reducePtxtSpace()

```
void helib::Ctxt::reducePtxtSpace (
            long newPtxtSpace )
```

Reduce plaintext space to a divisor of the original plaintext space.

7.31.3.90 reLinearize()

```
void helib::Ctxt::reLinearize (
            long keyIdx = 0 )
```

7.31.3.91 setPtxtMag()

```
void helib::Ctxt::setPtxtMag (
            const NTL::xdouble & z ) [inline]
```

7.31.3.92 smartAutomorph()

```
void helib::Ctxt::smartAutomorph (
            long k )
```

automorphism with re-linearization

7.31.3.93 square()

```
void helib::Ctxt::square ( )  [inline]
```

7.31.3.94 write()

```
void helib::Ctxt::write (
            std::ostream & str ) const
```

7.31.3.95 xorConstant() [1/2]

```
void helib::Ctxt::xorConstant (
            const DoubleCRT & poly,
            UNUSED double size = -1.0 )  [inline]
```

Convenience method: XOR and nXOR with arbitrary plaintext space: a xor b = a+b-2ab = a + (1-2a)*b, a nxor b = 1-a-b+2ab = (b-1)(2a-1)+a

7.31.3.96 xorConstant() [2/2]

```
void helib::Ctxt::xorConstant (
            const NTL::ZZX & poly,
            double size = -1.0 )  [inline]
```

7.31.4 Friends And Related Function Documentation

7.31.4.1 BasicAutomorphPrecon

```
friend class BasicAutomorphPrecon  [friend]
```

7.31.4.2 operator<<

```
std::ostream& operator<< (
            std::ostream & str,
            const Ctxt & ctxt )  [friend]
```

7.31.4.3 operator>>

```
std::istream& operator>> (
            std::istream & str,
            Ctxt & ctxt )  [friend]
```

7.31.4.4 PubKey

```
friend class PubKey  [friend]
```

7.31.4.5 SecKey

```
friend class SecKey  [friend]
```

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

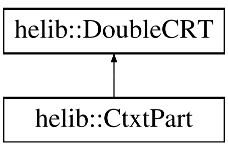
- /HElib/include/helib/Ctxt.h
- /HElib/src/Ctxt.cpp
- /HElib/src/polyEval.cpp

7.32 helib::CtxtPart Class Reference

One entry in a ciphertext std::vector.

```
#include <Ctxt.h>
```

Inheritance diagram for helib::CtxtPart:



Public Member Functions

- bool operator== (const CtxtPart &other) const
- bool operator!= (const CtxtPart &other) const
- CtxtPart (const Context &_context, const IndexSet &s)
- CtxtPart (const Context &_context, const IndexSet &s, const SKHandle &otherHandle)
- CtxtPart (const DoubleCRT &other)
- CtxtPart (const DoubleCRT &other, const SKHandle &otherHandle)
- void read (std::istream &str)
- void write (std::ostream &str) const

Public Attributes

- SKHandle skHandle

  The handle is a public data member.

7.32.1 Detailed Description

One entry in a ciphertext std::vector.

A ciphertext part consists of a polynomial (element of the ring R_Q) and a handle to the corresponding secret-key polynomial.

7.32.2 Constructor & Destructor Documentation

7.32.2.1 CtxtPart() [1/4]

```
helib::CtxtPart::CtxtPart (
            const Context & _context,
            const IndexSet & s )  [inline]
```

7.32.2.2 CtxtPart() [2/4]

```
helib::CtxtPart::CtxtPart (
            const Context & _context,
            const IndexSet & s,
            const SKHandle & otherHandle )  [inline]
```

7.32.2.3 CtxtPart() [3/4]

```
helib::CtxtPart::CtxtPart (
            const DoubleCRT & other )  [inline], [explicit]
```

7.32.2.4 CtxtPart() [4/4]

```
helib::CtxtPart::CtxtPart (
            const DoubleCRT & other,
            const SKHandle & otherHandle )  [inline]
```

7.32.3 Member Function Documentation

7.32.3.1 operator"!=()

```
bool helib::CtxtPart::operator!= (
            const CtxtPart & other ) const  [inline]
```

7.32.3.2 operator==()

```
bool helib::CtxtPart::operator== (
            const CtxtPart & other ) const
```

7.32.3.3 read()

```
void helib::CtxtPart::read (
            std::istream & str )
```

7.32.3.4 write()

```
void helib::CtxtPart::write (
            std::ostream & str ) const
```

7.32.4 Member Data Documentation

7.32.4.1 skHandle

`SKHandle helib::CtxtPart::skHandle`

The handle is a public data member.

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

- /HElib/include/helib/Ctxt.h
- /HElib/src/Ctxt.cpp

7.33 helib::CubeSignature Class Reference

Holds a vector of dimensions for a hypercube and some additional data.

`#include <hypercube.h>`

Public Member Functions

- CubeSignature ()
- void initSignature (const long _dims[ ], long _ndims)
- template< typename VecType >
  void initSignature (const VecType &_dims)
- CubeSignature (const long _dims[ ], long _ndims)
- CubeSignature (const NTL::Vec< long > &_dims)
- CubeSignature (const std::vector< long > &_dims)
- long getNumDims () const

  number of dimensions
- long getSize () const

  total size of cube
- long getDim (long d) const

  size of dimension d
- long getProd (long d) const

  product of sizes of dimensions d, d+1, ...
- long getProd (long from, long to) const

  product of sizes of dimensions from, from+1, ..., to-1
- long getCoord (long i, long d) const

  get coordinate in dimension d of index i
- long addCoord (long i, long d, long offset) const

  add offset to coordinate in dimension d of index i
- template< typename VecType >
  bool incrementCoords (VecType &v) const
- template< typename VecType >
  void getAllCoords (VecType &v, long i) const
- template< typename VecType >
  long assembleCoords (VecType &v) const
- long numSlices (long d=1) const

  number of slices
- long sliceSize (long d=1) const

  size of one slice
- long numCols () const

  number of columns
- std::pair< long, long > breakIndexByDim (long idx, long dim) const
- long assembleIndexByDim (std::pair< long, long > idx, long dim) const

  The inverse of breakIndexByDim.

Friends

- std::ostream & operator<< (std::ostream &s, const CubeSignature &sig)

7.33.1 Detailed Description

Holds a vector of dimensions for a hypercube and some additional data.

7.33.2 Constructor & Destructor Documentation

7.33.2.1 CubeSignature() [1/4]

```
helib::CubeSignature::CubeSignature ( ) [inline]
```

7.33.2.2 CubeSignature() [2/4]

```
helib::CubeSignature::CubeSignature (
            const long _dims[],
            long _ndims ) [inline]
```

7.33.2.3 CubeSignature() [3/4]

```
helib::CubeSignature::CubeSignature (
            const NTL::Vec< long > & _dims ) [inline]
```

7.33.2.4 CubeSignature() [4/4]

```
helib::CubeSignature::CubeSignature (
            const std::vector< long > & _dims ) [inline]
```

7.33.3 Member Function Documentation

7.33.3.1 addCoord()

```
long helib::CubeSignature::addCoord (
            long i,
            long d,
            long offset ) const  [inline]
```

add offset to coordinate in dimension d of index i

7.33.3.2 assembleCoords()

```
template<typename VecType >
long helib::CubeSignature::assembleCoords (
            VecType & v ) const  [inline]
```

reconstruct index from its coordinates VecType is either std::vector<intType> or NTL:Vec<intType>

7.33.3.3 assembleIndexByDim()

```
long helib::CubeSignature::assembleIndexByDim (
            std::pair< long, long > idx,
            long dim ) const
```

The inverse of breakIndexByDim.

7.33.3.4 breakIndexByDim()

```
std::pair< long, long > helib::CubeSignature::breakIndexByDim (
            long idx,
            long dim ) const
```

Break an index into the hypercube to index of the dimension-dim subcube and index inside that subcube.

7.33.3.5 getAllCoords()

```
template<typename VecType >
void helib::CubeSignature::getAllCoords (
            VecType & v,
            long i ) const  [inline]
```

get the coordinates of index i in all dimensions. VecType is either std::vector<intType> or NTL:Vec<intType>

7.33.3.6 getCoord()

```
long helib::CubeSignature::getCoord (
            long i,
            long d ) const  [inline]
```

get coordinate in dimension d of index i

7.33.3.7 getDim()

```
long helib::CubeSignature::getDim (
            long d ) const  [inline]
```

size of dimension d

7.33.3.8 getNumDims()

```
long helib::CubeSignature::getNumDims ( ) const  [inline]
```

number of dimensions

7.33.3.9 getProd() [1/2]

```
long helib::CubeSignature::getProd (
            long d ) const  [inline]
```

product of sizes of dimensions d, d+1, ...

7.33.3.10 getProd() [2/2]

```
long helib::CubeSignature::getProd (
            long from,
            long to ) const  [inline]
```

product of sizes of dimensions from, from+1, ..., to-1

7.33.3.11 getSize()

```
long helib::CubeSignature::getSize ( ) const  [inline]
```

total size of cube

7.33.3.12 incrementCoords()

```
template<typename VecType >
bool helib::CubeSignature::incrementCoords (
            VecType & v ) const  [inline]
```

Increment the coordinates to point to next index, returning false if already at maximum value. VecType is either std::vector<intType> or NTL:Vec<intType>

7.33.3.13 initSignature() [1/2]

```
void helib::CubeSignature::initSignature (
            const long _dims[],
            long _ndims )  [inline]
```

7.33.3.14 initSignature() [2/2]

```
template<typename VecType >
void helib::CubeSignature::initSignature (
            const VecType & _dims )  [inline]
```

7.33.3.15 numCols()

```
long helib::CubeSignature::numCols ( ) const  [inline]
```

number of columns

7.33.3.16 numSlices()

```
long helib::CubeSignature::numSlices (
            long d = 1 ) const  [inline]
```

number of slices

7.33.3.17 sliceSize()

```
long helib::CubeSignature::sliceSize (
            long d = 1 ) const  [inline]
```

size of one slice

7.33.4 Friends And Related Function Documentation

7.33.4.1 operator<<

```
std::ostream& operator<< (
            std::ostream & s,
            const CubeSignature & sig )  [friend]
```

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

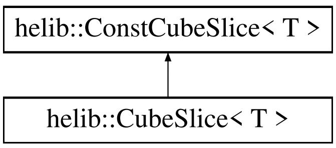
- /HElib/include/helib/hypercube.h
- /HElib/src/hypercube.cpp

7.34 helib::CubeSlice< T > Class Template Reference

A lower-dimension slice of a hypercube.

`#include <hypercube.h>`

Inheritance diagram for helib::CubeSlice< T >:



Public Member Functions

- CubeSlice (HyperCube< T > &_cube)
- CubeSlice (NTL::Vec< T > &_data, const CubeSignature &_sig)
- CubeSlice (const CubeSlice< T > &bigger, long i, long _dimOffset=1)
- CubeSlice (HyperCube< T > &_cube, long i, long _dimOffset=1)
- void copy (const ConstCubeSlice< T > &other) const
- T & at (long i) const
- T & operator[ ] (long i) const

7.34.1 Detailed Description

template<typename T>
class helib::CubeSlice< T >

A lower-dimension slice of a hypercube.

7.34.2 Constructor & Destructor Documentation

7.34.2.1 CubeSlice() [1/4]

```
template<typename T >
helib::CubeSlice< T >::CubeSlice (
            HyperCube< T > & _cube )  [inline], [explicit]
```

7.34.2.2 CubeSlice() [2/4]

```
template<typename T >
helib::CubeSlice< T >::CubeSlice (
            NTL::Vec< T > & _data,
            const CubeSignature & _sig )  [inline]
```

7.34.2.3 CubeSlice() [3/4]

```
template<typename T >
helib::CubeSlice< T >::CubeSlice (
            const CubeSlice< T > & bigger,
            long i,
            long _dimOffset = 1 )  [inline]
```

7.34.2.4 CubeSlice() [4/4]

```
template<typename T >
helib::CubeSlice< T >::CubeSlice (
            HyperCube< T > & _cube,
            long i,
            long _dimOffset = 1 )  [inline]
```

7.34.3 Member Function Documentation

7.34.3.1 at()

```
template<typename T >
T& helib::CubeSlice< T >::at (
            long i ) const  [inline]
```

7.34.3.2 copy()

```
template<typename T >
void helib::CubeSlice< T >::copy (
            const ConstCubeSlice< T > & other ) const
```

7.34.3.3 operator[]()

```
template<typename T >
T& helib::CubeSlice< T >::operator[] (
            long i ) const  [inline]
```

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

- /HElib/include/helib/hypercube.h
- /HElib/src/hypercube.cpp

7.35 helib::DAGnode Class Reference

A node in an addition-DAG structure.

Public Member Functions

- DAGnode (NodeIdx ii, bool qq, long lvl, long chl=0, DAGnode *pt1=nullptr, DAGnode *pt2=nullptr)
- DAGnode (DAGnode &&other)
- std::string nodeName () const

Public Attributes

- NodeIdx idx
- bool isQ
- long level
- std::atomic_long childrenLeft
- DAGnode * parent1
- DAGnode * parent2
- std::mutex ct_mtx
- Ctxt * ct

7.35.1 Detailed Description

A node in an addition-DAG structure.

7.35.2 Constructor & Destructor Documentation

7.35.2.1 DAGnode() [1/2]

```
helib::DAGnode::DAGnode (
            NodeIdx ii,
            bool qq,
            long lvl,
            long chl = 0,
            DAGnode * pt1 = nullptr,
            DAGnode * pt2 = nullptr )  [inline]
```

7.35.2.2 DAGnode() [2/2]

```
helib::DAGnode::DAGnode (
            DAGnode && other )  [inline]
```

7.35.3 Member Function Documentation

7.35.3.1 nodeName()

```
std::string helib::DAGnode::nodeName ( ) const  [inline]
```

7.35.4 Member Data Documentation

7.35.4.1 childrenLeft

`std::atomic_long helib::DAGnode::childrenLeft`

7.35.4.2 ct

`Ctxt* helib::DAGnode::ct`

7.35.4.3 ct_mtx

`std::mutex helib::DAGnode::ct_mtx`

7.35.4.4 idx

`NodeIdx helib::DAGnode::idx`

7.35.4.5 isQ

`bool helib::DAGnode::isQ`

7.35.4.6 level

`long helib::DAGnode::level`

7.35.4.7 parent1

`DAGnode* helib::DAGnode::parent1`

7.35.4.8 parent2

```
DAGnode * helib::DAGnode::parent2
```

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

- /HElib/src/binaryArith.cpp

7.36 helib::decode_pa_impl< type > Class Template Reference

Static Public Member Functions

- template< typename T >
  static void apply (const EncryptedArrayDerived< type > &ea, std::vector< T > &array, const PlaintextArray &pa)

7.36.1 Member Function Documentation

7.36.1.1 apply()

```
template<typename type >
template<typename T >
static void helib::decode_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            std::vector< T > & array,
            const PlaintextArray & pa )  [inline], [static]
```

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

- /HElib/src/EncryptedArray.cpp

7.37 helib::deep_clone< X > Class Template Reference

Deep copy: initialize with clone.

```
#include <clonedPtr.h>
```

Static Public Member Functions

- static X * apply (const X *x)

7.37.1 Detailed Description

template<typename X>
class helib::deep_clone< X >

Deep copy: initialize with clone.

Template Parameters

X	The class to which this points

7.37.2 Member Function Documentation

7.37.2.1 apply()

```
template<typename X >
static X* helib::deep_clone< X >::apply (
            const X * x ) [inline], [static]
```

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

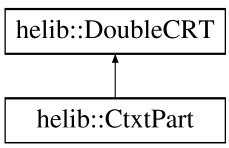
- /HElib/include/helib/clonedPtr.h

7.38 helib::DoubleCRT Class Reference

Implementing polynomials (elements in the ring R_Q) in double-CRT form.

```
#include <DoubleCRT.h>
```

Inheritance diagram for helib::DoubleCRT:



Public Member Functions

- DoubleCRT (const DoubleCRT &other)=default
- DoubleCRT (const NTL::ZZX &poly, const Context &_context, const IndexSet &indexSet)

  Initializing DoubleCRT from a ZZX polynomial.
- DoubleCRT (const zzX &poly, const Context &_context, const IndexSet &indexSet)

  Same as above, but with zzX's.
- DoubleCRT (const Context &_context, const IndexSet &indexSet)

  Also specify the IndexSet explicitly.
- DoubleCRT & operator= (const DoubleCRT &other)
- DoubleCRT & operator= (const zzX &poly)
- DoubleCRT & operator= (const NTL::ZZX &poly)
- DoubleCRT & operator= (const NTL::ZZ &num)
- DoubleCRT & operator= (const long num)
- long getOneRow (NTL::Vec< long > &row, long idx, bool positive=false) const

Get one row of a polynomial.
- long getOneRow (NTL::zz_pX &row, long idx) const
- void toPoly (NTL::ZZX &p, const IndexSet &s, bool positive=false) const

  Recovering the polynomial in coefficient representation. This yields an integer polynomial with coefficients in [-P/2,P/2], unless the positive flag is set to true, in which case we get coefficients in [0,P-1] (P is the product of all moduli used). Using the optional IndexSet param we compute the polynomial reduced modulo the product of only the primes in that set.
- void toPoly (NTL::ZZX &p, bool positive=false) const
- bool operator== (const DoubleCRT &other) const
- bool operator!= (const DoubleCRT &other) const
- DoubleCRT & SetZero ()
- DoubleCRT & SetOne ()
- NTL::xdouble breakIntoDigits (std::vector< DoubleCRT > &dgts) const

  Break into n digits,according to the primeSets in context.digits. See Section 3.1.6 of the design document (re-linearization) Returns the sum of the canonical embedding of the digits.
- void addPrimes (const IndexSet &s1, NTL::ZZX ∗poly_p=0)

  Expand the index set by s1. It is assumed that s1 is disjoint from the current index set. If poly_p != 0, then ∗poly_p will first be set to the result of applying toPoly.
- double addPrimesAndScale (const IndexSet &s1)

  Expand index set by s1, and multiply by Prod_{q in s1}. s1 is disjoint from the current index set, returns log(product).
- void removePrimes (const IndexSet &s1)

  Remove s1 from the index set.
- void setPrimes (const IndexSet &s1)

  @ brief make prime set equal to s1
- const Context & getContext () const
- const IndexMap< NTL::vec_long > & getMap () const
- const IndexSet & getIndexSet () const
- void randomize (const NTL::ZZ ∗seed=nullptr)

  Fills each row i with random ints mod pi, uses NTL's PRG.
- double sampleSmall ()

  Coefficients are -1/0/1, Prob[0]=1/2.
- double sampleSmallBounded ()
- double sampleHWt (long Hwt)

  Coefficients are -1/0/1 with pre-specified number of nonzeros.
- double sampleHWtBounded (long Hwt)
- double sampleGaussian (double stdev=0.0)

  Coefficients are Gaussians Return a high probability bound on L-infty norm of canonical embedding.
- double sampleGaussianBounded (double stdev=0.0)
- double sampleUniform (long B)

  Coefficients are uniform in [-B..B].
- NTL::xdouble sampleUniform (const NTL::ZZ &B)
- void scaleDownToSet (const IndexSet &s, long ptxtSpace, NTL::ZZX &delta)
- void FFT (const NTL::ZZX &poly, const IndexSet &s)
- void FFT (const zzX &poly, const IndexSet &s)
- void reduce () const
- void read (std::istream &str)
- void write (std::ostream &str) const

Arithmetic operation

Only the "destructive" versions are used, i.e., a += b is implemented but not a + b.

- DoubleCRT & Negate (const DoubleCRT &other)
- DoubleCRT & Negate ()
- DoubleCRT & operator+= (const DoubleCRT &other)

- DoubleCRT & operator+= (const NTL::ZZX &poly)
- DoubleCRT & operator+= (const NTL::ZZ &num)
- DoubleCRT & operator+= (long num)
- DoubleCRT & operator-= (const DoubleCRT &other)
- DoubleCRT & operator-= (const NTL::ZZX &poly)
- DoubleCRT & operator-= (const NTL::ZZ &num)
- DoubleCRT & operator-= (long num)
- DoubleCRT & operator++ ()
- DoubleCRT & operator-- ()
- void operator++ (int)
- void operator-- (int)
- DoubleCRT & operator*= (const DoubleCRT &other)
- DoubleCRT & operator*= (const NTL::ZZX &poly)
- DoubleCRT & operator*= (const NTL::ZZ &num)
- DoubleCRT & operator*= (long num)
- void Add (const DoubleCRT &other, bool matchIndexSets=true)
- void Sub (const DoubleCRT &other, bool matchIndexSets=true)
- void Mul (const DoubleCRT &other, bool matchIndexSets=true)
- DoubleCRT & operator/= (const NTL::ZZ &num)
- DoubleCRT & operator/= (long num)
- void Exp (long k)

  Small-exponent polynomial exponentiation.
- void automorph (long k)

  Apply the automorphism F(X) --> F(X^k) (with gcd(k,m)=1)
- DoubleCRT & operator>>= (long k)
- void complexConj ()

  Compute the complex conjugate, the same as automorph(m-1)

Friends

- std::ostream & operator<< (std::ostream &s, const DoubleCRT &d)
- std::istream & operator>> (std::istream &s, DoubleCRT &d)

7.38.1 Detailed Description

Implementing polynomials (elements in the ring R_Q) in double-CRT form.

Double-CRT form is a matrix of L rows and phi(m) columns. The i'th row contains the FFT of the element wrt the ith prime, i.e. the evaluations of the polynomial at the primitive mth roots of unity mod the ith prime. The polynomial thus represented is defined modulo the product of all the primes in use.

The list of primes is defined by the data member indexMap. indexMap.getIndexSet() defines the set of indices of primes associated with this DoubleCRT object: they index the primes stored in the associated Context.

Arithmetic operations are computed modulo the product of the primes in use and also modulo Phi_m(X). Arithmetic operations can only be applied to DoubleCRT objects relative to the same context, trying to add/multiply objects that have different Context objects will raise an error.

7.38.2 Constructor & Destructor Documentation

7.38.2.1 DoubleCRT() [1/4]

```
helib::DoubleCRT::DoubleCRT (
            const DoubleCRT & other )  [default]
```

7.38.2.2 DoubleCRT() [2/4]

```
helib::DoubleCRT::DoubleCRT (
            const NTL::ZZX & poly,
            const Context & _context,
            const IndexSet & indexSet )
```

Initializing DoubleCRT from a ZZX polynomial.

Parameters

poly	The ring element itself, zero if not specified
_context	The context for this DoubleCRT object, use "current active context" if not specified
indexSet	Which primes to use for this object, if not specified then use all of them

7.38.2.3 DoubleCRT() [3/4]

```
helib::DoubleCRT::DoubleCRT (
            const zzX & poly,
            const Context & _context,
            const IndexSet & indexSet )
```

Same as above, but with zzX's.

7.38.2.4 DoubleCRT() [4/4]

```
helib::DoubleCRT::DoubleCRT (
            const Context & _context,
            const IndexSet & indexSet )
```

Also specify the IndexSet explicitly.

7.38.3 Member Function Documentation

7.38.3.1 Add()

```
void helib::DoubleCRT::Add (
            const DoubleCRT & other,
            bool matchIndexSets = true )  [inline]
```

7.38.3.2 addPrimes()

```
void helib::DoubleCRT::addPrimes (
            const IndexSet & s1,
            NTL::ZZX * poly_p = 0 )
```

Expand the index set by s1. It is assumed that s1 is disjoint from the current index set. If poly_p != 0, then ∗poly_p will first be set to the result of applying toPoly.

7.38.3.3 addPrimesAndScale()

```
double helib::DoubleCRT::addPrimesAndScale (
            const IndexSet & s1 )
```

Expand index set by s1, and multiply by Prod_{q in s1}. s1 is disjoint from the current index set, returns log(product).

7.38.3.4 automorph()

```
void helib::DoubleCRT::automorph (
            long k )
```

Apply the automorphism F(X) --> F(X^k) (with gcd(k,m)=1)

7.38.3.5 breakIntoDigits()

```
NTL::xdouble helib::DoubleCRT::breakIntoDigits (
            std::vector< DoubleCRT > & dgts ) const
```

Break into n digits,according to the primeSets in context.digits. See Section 3.1.6 of the design document (re-linearization) Returns the sum of the canonical embedding of the digits.

7.38.3.6 complexConj()

```
void helib::DoubleCRT::complexConj ( )
```

Compute the complex conjugate, the same as automorph(m-1)

7.38.3.7 Exp()

```
void helib::DoubleCRT::Exp (
            long k )
```

Small-exponent polynomial exponentiation.

7.38.3.8 FFT() [1/2]

```
void helib::DoubleCRT::FFT (
            const NTL::ZZX & poly,
            const IndexSet & s )
```

7.38.3.9 FFT() [2/2]

```
void helib::DoubleCRT::FFT (
            const zzX & poly,
            const IndexSet & s )
```

7.38.3.10 getContext()

```
const Context& helib::DoubleCRT::getContext ( ) const [inline]
```

7.38.3.11 getIndexSet()

```
const IndexSet& helib::DoubleCRT::getIndexSet ( ) const [inline]
```

7.38.3.12 getMap()

```
const IndexMap<NTL::vec_long>& helib::DoubleCRT::getMap ( ) const [inline]
```

7.38.3.13 getOneRow() [1/2]

```
long helib::DoubleCRT::getOneRow (
            NTL::Vec< long > & row,
            long idx,
            bool positive = false ) const
```

Get one row of a polynomial.

7.38.3.14 getOneRow() [2/2]

```
long helib::DoubleCRT::getOneRow (
            NTL::zz_pX & row,
            long idx ) const
```

7.38.3.15 Mul()

```
void helib::DoubleCRT::Mul (
            const DoubleCRT & other,
            bool matchIndexSets = true ) [inline]
```

7.38.3.16 Negate() [1/2]

```
DoubleCRT& helib::DoubleCRT::Negate ( ) [inline]
```

7.38.3.17 Negate() [2/2]

```
DoubleCRT & helib::DoubleCRT::Negate (
            const DoubleCRT & other )
```

7.38.3.18 operator"!=()

```
bool helib::DoubleCRT::operator!= (
            const DoubleCRT & other ) const [inline]
```

7.38.3.19 operator*=() [1/4]

```
DoubleCRT& helib::DoubleCRT::operator*= (
            const DoubleCRT & other ) [inline]
```

7.38.3.20 operator*=() [2/4]

```
DoubleCRT& helib::DoubleCRT::operator*= (
            const NTL::ZZ & num ) [inline]
```

7.38.3.21 operator*=() [3/4]

```
DoubleCRT& helib::DoubleCRT::operator*= (
            const NTL::ZZX & poly ) [inline]
```

7.38.3.22 operator*=() [4/4]

```
DoubleCRT& helib::DoubleCRT::operator*= (
            long num ) [inline]
```

7.38.3.23 operator++() [1/2]

```
DoubleCRT& helib::DoubleCRT::operator++ ( ) [inline]
```

7.38.3.24 operator++() [2/2]

```
void helib::DoubleCRT::operator++ (
            int ) [inline]
```

7.38.3.25 operator+=() [1/4]

```
DoubleCRT& helib::DoubleCRT::operator+= (
            const DoubleCRT & other ) [inline]
```

7.38.3.26 operator+=() [2/4]

```
DoubleCRT& helib::DoubleCRT::operator+= (
            const NTL::ZZ & num ) [inline]
```

7.38.3.27 operator+=() [3/4]

```
DoubleCRT& helib::DoubleCRT::operator+= (
            const NTL::ZZX & poly ) [inline]
```

7.38.3.28 operator+=() [4/4]

```
DoubleCRT& helib::DoubleCRT::operator+= (
            long num ) [inline]
```

7.38.3.29 operator--() [1/2]

```
DoubleCRT& helib::DoubleCRT::operator-- ( ) [inline]
```

7.38.3.30 operator--() [2/2]

```
void helib::DoubleCRT::operator-- (
            int ) [inline]
```

7.38.3.31 operator-=() [1/4]

```
DoubleCRT& helib::DoubleCRT::operator-= (
            const DoubleCRT & other ) [inline]
```

7.38.3.32 operator-=() [2/4]

```
DoubleCRT& helib::DoubleCRT::operator-= (
            const NTL::ZZ & num ) [inline]
```

7.38.3.33 operator-=() [3/4]

```
DoubleCRT& helib::DoubleCRT::operator-= (
            const NTL::ZZX & poly ) [inline]
```

7.38.3.34 operator-=() [4/4]

```
DoubleCRT& helib::DoubleCRT::operator-= (
            long num ) [inline]
```

7.38.3.35 operator/=() [1/2]

```
DoubleCRT & helib::DoubleCRT::operator/= (
            const NTL::ZZ & num )
```

7.38.3.36 operator/=() [2/2]

```
DoubleCRT& helib::DoubleCRT::operator/= (
            long num ) [inline]
```

7.38.3.37 operator=() [1/5]

```
DoubleCRT & helib::DoubleCRT::operator= (
             const DoubleCRT & other )
```

7.38.3.38 operator=() [2/5]

```
DoubleCRT& helib::DoubleCRT::operator= (
             const long num )  [inline]
```

7.38.3.39 operator=() [3/5]

```
DoubleCRT & helib::DoubleCRT::operator= (
             const NTL::ZZ & num )
```

7.38.3.40 operator=() [4/5]

```
DoubleCRT & helib::DoubleCRT::operator= (
             const NTL::ZZX & poly )
```

7.38.3.41 operator=() [5/5]

```
DoubleCRT & helib::DoubleCRT::operator= (
             const zzX & poly )
```

7.38.3.42 operator==()

```
bool helib::DoubleCRT::operator== (
             const DoubleCRT & other ) const  [inline]
```

7.38.3.43 operator>>=()

```
DoubleCRT& helib::DoubleCRT::operator>>= (
             long k )  [inline]
```

7.38.3.44 randomize()

```
void helib::DoubleCRT::randomize (
            const NTL::ZZ * seed = nullptr )
```

Fills each row i with random ints mod pi, uses NTL's PRG.

7.38.3.45 read()

```
void helib::DoubleCRT::read (
            std::istream & str )
```

7.38.3.46 reduce()

```
void helib::DoubleCRT::reduce ( ) const  [inline]
```

7.38.3.47 removePrimes()

```
void helib::DoubleCRT::removePrimes (
            const IndexSet & s1 )  [inline]
```

Remove s1 from the index set.

7.38.3.48 sampleGaussian()

```
double helib::DoubleCRT::sampleGaussian (
            double stdev = 0.0 )
```

Coefficients are Gaussians Return a high probability bound on L-infty norm of canonical embedding.

7.38.3.49 sampleGaussianBounded()

```
double helib::DoubleCRT::sampleGaussianBounded (
            double stdev = 0.0 )
```

7.38.3.50 sampleHWt()

```
double helib::DoubleCRT::sampleHWt (
            long Hwt )
```

Coefficients are -1/0/1 with pre-specified number of nonzeros.

7.38.3.51 sampleHWtBounded()

```
double helib::DoubleCRT::sampleHWtBounded (
            long Hwt )
```

7.38.3.52 sampleSmall()

```
double helib::DoubleCRT::sampleSmall ( )
```

Coefficients are -1/0/1, Prob[0]=1/2.

Sampling routines: Each of these return a high probability bound on L-infty norm of canonical embedding

7.38.3.53 sampleSmallBounded()

```
double helib::DoubleCRT::sampleSmallBounded ( )
```

7.38.3.54 sampleUniform() [1/2]

```
NTL::xdouble helib::DoubleCRT::sampleUniform (
            const NTL::ZZ & B )
```

7.38.3.55 sampleUniform() [2/2]

```
double helib::DoubleCRT::sampleUniform (
            long B )
```

Coefficients are uniform in [-B..B].

7.38.3.56 scaleDownToSet()

```
void helib::DoubleCRT::scaleDownToSet (
            const IndexSet & s,
            long ptxtSpace,
            NTL::ZZX & delta )
```

7.38.3.57 SetOne()

```
DoubleCRT& helib::DoubleCRT::SetOne ( )  [inline]
```

7.38.3.58 setPrimes()

```
void helib::DoubleCRT::setPrimes (
            const IndexSet & s1 )  [inline]
```

@ brief make prime set equal to s1

7.38.3.59 SetZero()

```
DoubleCRT& helib::DoubleCRT::SetZero ( )  [inline]
```

7.38.3.60 Sub()

```
void helib::DoubleCRT::Sub (
            const DoubleCRT & other,
            bool matchIndexSets = true )  [inline]
```

7.38.3.61 toPoly() [1/2]

```
void helib::DoubleCRT::toPoly (
            NTL::ZZX & p,
            bool positive = false ) const
```

7.38.3.62 toPoly() [2/2]

```
void helib::DoubleCRT::toPoly (
            NTL::ZZX & p,
            const IndexSet & s,
            bool positive = false ) const
```

Recovering the polynomial in coefficient representation. This yields an integer polynomial with coefficients in [-P/2,P/2], unless the positive flag is set to true, in which case we get coefficients in [0,P-1] (P is the product of all moduli used). Using the optional IndexSet param we compute the polynomial reduced modulo the product of only the primes in that set.

7.38.3.63 write()

```
void helib::DoubleCRT::write (
            std::ostream & str ) const
```

7.38.4 Friends And Related Function Documentation

7.38.4.1 operator<<

```
std::ostream& operator<< (
            std::ostream & s,
            const DoubleCRT & d ) [friend]
```

7.38.4.2 operator>>

```
std::istream& operator>> (
            std::istream & s,
            DoubleCRT & d ) [friend]
```

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

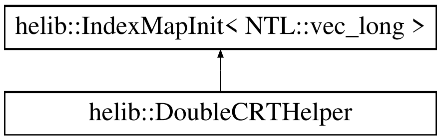
- /HElib/include/helib/DoubleCRT.h
- /HElib/src/DoubleCRT.cpp

7.39 helib::DoubleCRTHelper Class Reference

A helper class to enforce consistency within an DoubleCRTHelper object.

```
#include <DoubleCRT.h>
```

Inheritance diagram for helib::DoubleCRTHelper:



Public Member Functions

- DoubleCRTHelper (const Context &context)
- virtual void init (NTL::vec_long &v)

    the init method ensures that all rows have the same size
- virtual IndexMapInit$<$ NTL::vec_long $>$ $*$ clone () const

    clone allocates a new object and copies the content

7.39.1 Detailed Description

A helper class to enforce consistency within an DoubleCRTHelper object.

See Section 2.6.2 of the design document (IndexMap)

7.39.2 Constructor & Destructor Documentation

7.39.2.1 DoubleCRTHelper()

```
helib::DoubleCRTHelper::DoubleCRTHelper (
            const Context & context )
```

7.39.3 Member Function Documentation

7.39.3.1 clone()

```
virtual IndexMapInit<NTL::vec_long>* helib::DoubleCRTHelper::clone ( ) const  [inline], [virtual]
```

clone allocates a new object and copies the content

7.39.3.2 init()

```
virtual void helib::DoubleCRTHelper::init (
            NTL::vec_long & v )  [inline], [virtual]
```

the init method ensures that all rows have the same size

Implements helib::IndexMapInit< NTL::vec_long >.

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

- /HElib/include/helib/DoubleCRT.h
- /HElib/src/DoubleCRT.cpp

7.40 helib::DynamicCtxtPowers Class Reference

Store powers of X, compute them dynamically as needed.

`#include <polyEval.h>`

Public Member Functions

- DynamicCtxtPowers (const Ctxt &c, long nPowers)
- Ctxt & getPower (long e)

    Returns the e'th power, computing it as needed.
- Ctxt & at (long i)

    dp.at(i) and dp[i] both return the i+1st power
- Ctxt & operator[ ] (long i)
- const std::vector< Ctxt > & getVector () const
- long size () const
- bool isPowerComputed (long i)

7.40.1 Detailed Description

Store powers of X, compute them dynamically as needed.

7.40.2 Constructor & Destructor Documentation

7.40.2.1 DynamicCtxtPowers()

```
helib::DynamicCtxtPowers::DynamicCtxtPowers (
            const Ctxt & c,
            long nPowers )  [inline]
```

7.40.3 Member Function Documentation

7.40.3.1 at()

```
Ctxt& helib::DynamicCtxtPowers::at (
             long i )  [inline]
```

dp.at(i) and dp[i] both return the i+1st power

7.40.3.2 getPower()

```
Ctxt & helib::DynamicCtxtPowers::getPower (
             long e )
```

Returns the e'th power, computing it as needed.

7.40.3.3 getVector()

```
const std::vector<Ctxt>& helib::DynamicCtxtPowers::getVector ( ) const  [inline]
```

7.40.3.4 isPowerComputed()

```
bool helib::DynamicCtxtPowers::isPowerComputed (
             long i )  [inline]
```

7.40.3.5 operator[]()

```
Ctxt& helib::DynamicCtxtPowers::operator[] (
             long i )  [inline]
```

7.40.3.6 size()

```
long helib::DynamicCtxtPowers::size ( ) const  [inline]
```

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

- /HElib/include/helib/polyEval.h
- /HElib/src/polyEval.cpp

7.41 helib::encode_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, const std::vector< long > &array)
- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, const std::vector< NTL↵ ::ZZX > &array)

7.41.1 Member Function Documentation

7.41.1.1 apply() [1/2]

```
template<typename type >
static void helib::encode_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            const std::vector< long > & array ) [inline], [static]
```

7.41.1.2 apply() [2/2]

```
template<typename type >
static void helib::encode_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            const std::vector< NTL::ZZX > & array ) [inline], [static]
```

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

- /HElib/src/EncryptedArray.cpp

7.42 helib::EncryptedArray Class Reference

A simple wrapper for a smart pointer to an EncryptedArrayBase. This is the interface that higher-level code should use.

```
#include <EncryptedArray.h>
```

Public Member Functions

- EncryptedArray (const Context &context, const NTL::ZZX &G=NTL::ZZX(1, 1))

    constructor: G defaults to the monomial X, PAlgebraMod from context
- EncryptedArray (const Context &context, const PAlgebraMod &_alMod)

    constructor: G defaults to F0, PAlgebraMod explicitly given
- EncryptedArray & operator= (const EncryptedArray &other)
- template< typename type >
  const EncryptedArrayDerived< type > & getDerived (type) const

    downcast operator example: const EncryptedArrayDerived<PA_GF2>& rep = ea.getDerived(PA_GF2());
- const EncryptedArrayCx & getCx () const

Direct access to EncryptedArrayBase methods

- PA_tag getTag () const
- template< template< typename > class T, typename... Args>
  void dispatch (Args &&... args) const
- const Context & getContext () const
- const PAlgebraMod & getAlMod () const
- const PAlgebra & getPAlgebra () const
- long getDegree () const
- void rotate (Ctxt &ctxt, long k) const
- void shift (Ctxt &ctxt, long k) const
- void rotate1D (Ctxt &ctxt, long i, long k, bool dc=false) const
- void shift1D (Ctxt &ctxt, long i, long k) const
- void badDimensionAutomorphCorrection (Ctxt &ctxt, long i, long amt) const
- template< typename PTXT , typename ARRAY >
  void encode (PTXT &ptxt, const ARRAY &array) const
- void encodeUnitSelector (zzX &ptxt, long i) const
- template< typename PTXT , typename ARRAY >
  void decode (ARRAY &array, const PTXT &ptxt) const
- template< typename T >
  void random (std::vector< T > &array) const
- template< typename T >
  void encrypt (Ctxt &ctxt, const PubKey &pKey, const T &ptxt) const
- template< typename T >
  void decrypt (const Ctxt &ctxt, const SecKey &sKey, T &ptxt) const
- void buildLinPolyCoeffs (std::vector< NTL::ZZX > &C, const std::vector< NTL::ZZX > &L) const
- void restoreContext () const
- void restoreContextForG () const
- long size () const
- long dimension () const
- long sizeOfDimension (long i) const
- long nativeDimension (long i) const
- long coordinate (long i, long k) const
- long addCoord (long i, long k, long offset) const
- template< typename U >
  void rotate1D (std::vector< U > &out, const std::vector< U > &in, long i, long offset) const

    rotate an array by offset in the i'th dimension (output should not alias input)

7.42.1 Detailed Description

A simple wrapper for a smart pointer to an EncryptedArrayBase. This is the interface that higher-level code should use.

7.42.2 Constructor & Destructor Documentation

7.42.2.1 EncryptedArray() [1/2]

```
helib::EncryptedArray::EncryptedArray (
            const Context & context,
            const NTL::ZZX & G = NTL::ZZX(1, 1) )  [inline]
```

constructor: G defaults to the monomial X, PAlgebraMod from context

7.42.2.2 EncryptedArray() [2/2]

```
helib::EncryptedArray::EncryptedArray (
            const Context & context,
            const PAlgebraMod & _alMod )  [inline]
```

constructor: G defaults to F0, PAlgebraMod explicitly given

7.42.3 Member Function Documentation

7.42.3.1 addCoord()

```
long helib::EncryptedArray::addCoord (
            long i,
            long k,
            long offset ) const  [inline]
```

7.42.3.2 badDimensionAutomorphCorrection()

```
void helib::EncryptedArray::badDimensionAutomorphCorrection (
            Ctxt & ctxt,
            long i,
            long amt ) const  [inline]
```

7.42.3.3 buildLinPolyCoeffs()

```
void helib::EncryptedArray::buildLinPolyCoeffs (
            std::vector< NTL::ZZX > & C,
            const std::vector< NTL::ZZX > & L ) const [inline]
```

7.42.3.4 coordinate()

```
long helib::EncryptedArray::coordinate (
            long i,
            long k ) const [inline]
```

7.42.3.5 decode()

```
template<typename PTXT , typename ARRAY >
void helib::EncryptedArray::decode (
            ARRAY & array,
            const PTXT & ptxt ) const [inline]
```

7.42.3.6 decrypt()

```
template<typename T >
void helib::EncryptedArray::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            T & ptxt ) const [inline]
```

7.42.3.7 dimension()

```
long helib::EncryptedArray::dimension ( ) const [inline]
```

7.42.3.8 dispatch()

```
template<template< typename > class T, typename... Args>
void helib::EncryptedArray::dispatch (
            Args &&... args ) const [inline]
```

7.42.3.9 encode()

```
template<typename PTXT , typename ARRAY >
void helib::EncryptedArray::encode (
            PTXT & ptxt,
            const ARRAY & array ) const [inline]
```

7.42.3.10 encodeUnitSelector()

```
void helib::EncryptedArray::encodeUnitSelector (
            zzX & ptxt,
            long i ) const [inline]
```

7.42.3.11 encrypt()

```
template<typename T >
void helib::EncryptedArray::encrypt (
            Ctxt & ctxt,
            const PubKey & pKey,
            const T & ptxt ) const [inline]
```

7.42.3.12 getAlMod()

```
const PAlgebraMod& helib::EncryptedArray::getAlMod ( ) const [inline]
```

7.42.3.13 getContext()

```
const Context& helib::EncryptedArray::getContext ( ) const [inline]
```

7.42.3.14 getCx()

```
const EncryptedArrayCx& helib::EncryptedArray::getCx ( ) const [inline]
```

7.42.3.15 getDegree()

```
long helib::EncryptedArray::getDegree ( ) const [inline]
```

7.42.3.16 getDerived()

```
template<typename type >
const EncryptedArrayDerived<type>& helib::EncryptedArray::getDerived (
            type ) const [inline]
```

downcast operator example: const EncryptedArrayDerived<PA_GF2>& rep = ea.getDerived(PA_GF2());

7.42.3.17 getPAlgebra()

```
const PAlgebra& helib::EncryptedArray::getPAlgebra ( ) const [inline]
```

7.42.3.18 getTag()

```
PA_tag helib::EncryptedArray::getTag ( ) const [inline]
```

7.42.3.19 nativeDimension()

```
long helib::EncryptedArray::nativeDimension (
            long i ) const [inline]
```

7.42.3.20 operator=()

```
EncryptedArray& helib::EncryptedArray::operator= (
            const EncryptedArray & other ) [inline]
```

7.42.3.21 random()

```
template<typename T >
void helib::EncryptedArray::random (
            std::vector< T > & array ) const [inline]
```

7.42.3.22 restoreContext()

```
void helib::EncryptedArray::restoreContext ( ) const [inline]
```

7.42.3.23 restoreContextForG()

```
void helib::EncryptedArray::restoreContextForG ( ) const [inline]
```

7.42.3.24 rotate()

```
void helib::EncryptedArray::rotate (
            Ctxt & ctxt,
            long k ) const [inline]
```

7.42.3.25 rotate1D() [1/2]

```
void helib::EncryptedArray::rotate1D (
            Ctxt & ctxt,
            long i,
            long k,
            bool dc = false ) const [inline]
```

7.42.3.26 rotate1D() [2/2]

```
template<typename U >
void helib::EncryptedArray::rotate1D (
            std::vector< U > & out,
            const std::vector< U > & in,
            long i,
            long offset ) const [inline]
```

rotate an array by offset in the i'th dimension (output should not alias input)

7.42.3.27 shift()

```
void helib::EncryptedArray::shift (
            Ctxt & ctxt,
            long k ) const [inline]
```

7.42.3.28 shift1D()

```
void helib::EncryptedArray::shift1D (
            Ctxt & ctxt,
            long i,
            long k ) const  [inline]
```

7.42.3.29 size()

```
long helib::EncryptedArray::size ( ) const  [inline]
```

7.42.3.30 sizeOfDimension()

```
long helib::EncryptedArray::sizeOfDimension (
            long i ) const  [inline]
```

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

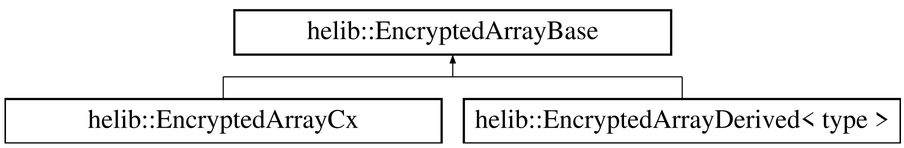
- /HElib/include/helib/EncryptedArray.h

7.43 helib::EncryptedArrayBase Class Reference

virtual class for data-movement operations on arrays of slots

```
#include <EncryptedArray.h>
```

Inheritance diagram for helib::EncryptedArrayBase:



Public Member Functions

- virtual ~EncryptedArrayBase ()
- virtual EncryptedArrayBase * clone () const =0
- virtual PA_tag getTag () const =0
- virtual const Context & getContext () const =0
- virtual const PAlgebra & getPAlgebra () const =0
- virtual long getDegree () const =0
- virtual long getP2R () const =0
- virtual void rotate (Ctxt &ctxt, long k) const =0

    Right rotation as a linear array. E.g., rotating ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(n 1 2 ... n-1)
- virtual void shift (Ctxt &ctxt, long k) const =0

    Non-cyclic right shift with zero fill E.g., shifting ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(0 1 2... n-1)
- virtual void rotate1D (Ctxt &ctxt, long i, long k, bool dc=false) const =0

    right-rotate k positions along the i'th dimension
- virtual void shift1D (Ctxt &ctxt, long i, long k) const =0

    Right shift k positions along the i'th dimension with zero fill.
- virtual void badDimensionAutomorphCorrection (Ctxt &ctxt, long i, long amt) const =0

    Correct an automorphism in a bad dimension.
- virtual void buildLinPolyCoeffs (std::vector< NTL::ZZX > &C, const std::vector< NTL::ZZX > &L) const =0

    Linearized polynomials. L describes a linear map M by describing its action on the standard power basis: M(x^j mod G) = (L[j] mod G), for j = 0..d-1. The result is a coefficient std::vector C for the linearized polynomial representing M: a polynomial h in Z/(p^r)[X] of degree < d is sent to.
- virtual void restoreContext () const
- virtual void restoreContextForG () const
- long size () const

    Total size (# of slots) of hypercube.
- long dimension () const

    Number of dimensions of hypercube.
- long sizeOfDimension (long i) const

    Size of given dimension.
- bool nativeDimension (long i) const

    Is rotations in given dimension a "native" operation?
- long coordinate (long i, long k) const

    returns coordinate of index k along the i'th dimension
- long addCoord (long i, long k, long offset) const

    adds offset to index k in the i'th dimension
- template< typename U >
  void rotate1D (std::vector< U > &out, const std::vector< U > &in, long i, long offset) const

    rotate an array by offset in the i'th dimension (output should not alias input)

Encoding/decoding methods

- virtual void encode (zzX &ptxt, const std::vector< long > &array) const =0
- virtual void encode (NTL::ZZX &ptxt, const std::vector< long > &array) const =0
- virtual void encode (zzX &ptxt, const std::vector< zzX > &array) const =0
- virtual void encode (zzX &ptxt, const PlaintextArray &array) const =0
- virtual void encode (NTL::ZZX &ptxt, const std::vector< NTL::ZZX > &array) const =0
- virtual void encode (NTL::ZZX &ptxt, const PlaintextArray &array) const =0
- void encode (zzX &ptxt, const std::vector< NTL::ZZX > &array) const
- virtual void decode (std::vector< long > &array, const NTL::ZZX &ptxt) const =0
- virtual void decode (std::vector< NTL::ZZX > &array, const NTL::ZZX &ptxt) const =0
- virtual void decode (PlaintextArray &array, const NTL::ZZX &ptxt) const =0
- virtual void random (std::vector< long > &array) const =0
- virtual void random (std::vector< NTL::ZZX > &array) const =0

- long decode1Slot (const NTL::ZZX &ptxt, long i) const
- void decode1Slot (NTL::ZZX &slot, const NTL::ZZX &ptxt, long i) const
- virtual void encodeUnitSelector (zzX &ptxt, long i) const =0

    Encodes a std::vector with 1 at position i and 0 everywhere else.

Encoding+encryption/decryption+decoding

- template< typename PTXT >
  void encrypt (Ctxt &ctxt, const PubKey &key, const PTXT &ptxt) const
- virtual void decrypt (const Ctxt &ctxt, const SecKey &sKey, std::vector< long > &ptxt) const =0
- virtual void decrypt (const Ctxt &ctxt, const SecKey &sKey, std::vector< NTL::ZZX > &ptxt) const =0
- virtual void decrypt (const Ctxt &ctxt, const SecKey &sKey, PlaintextArray &ptxt) const =0
- virtual void decrypt (const Ctxt &ctxt, const SecKey &sKey, std::vector< double > &ptxt) const =0
- virtual void decrypt (const Ctxt &ctxt, const SecKey &sKey, std::vector< cx_double > &ptxt) const =0
- long decrypt1Slot (const Ctxt &ctxt, const SecKey &sKey, long i) const
- void decrypt1Slot (NTL::ZZX &slot, const Ctxt &ctxt, const SecKey &sKey, long i) const

7.43.1 Detailed Description

virtual class for data-movement operations on arrays of slots

An object ea of type EncryptedArray stores information about an Context context, and a monic polynomial G. If context defines parameters m, p, and r, then ea is a helper abject that supports encoding/decoding and encryption/decryption of std::vectors of plaintext slots over the ring (Z/(p^r)[X])/(G).

The polynomial G should be irreducible over Z/(p^r) (this is not checked). The degree of G should divide the multiplicative order of p modulo m (this is checked). Currently, the following restriction is imposed:

either r == 1 or deg(G) == 1 or G == factors[0].

ea stores objects in the polynomial ring Z/(p^r)[X].

Just as for the class PAlgebraMod, if p == 2 and r == 1, then these polynomials are represented as GF2X's, and otherwise as zz_pX's. Thus, the types of these objects are not determined until run time. As such, we need to use a class hierarchy, which mirrors that of PAlgebraMod, as follows.

EncryptedArrayBase is a virtual class

EncryptedArrayDerived<type> is a derived template class, where type is either PA_GF2 or PA_zz_p.

The class EncryptedArray is a simple wrapper around a smart pointer to an EncryptedArrayBase object: copying an EncryptedArray object results is a "deep copy" of the underlying object of the derived class.

7.43.2 Constructor & Destructor Documentation

7.43.2.1 ∼EncryptedArrayBase()

```
virtual helib::EncryptedArrayBase::∼EncryptedArrayBase ( ) [inline], [virtual]
```

7.43.3 Member Function Documentation

7.43.3.1 addCoord()

```
long helib::EncryptedArrayBase::addCoord (
            long i,
            long k,
            long offset ) const  [inline]
```

adds offset to index k in the i'th dimension

7.43.3.2 badDimensionAutomorphCorrection()

```
virtual void helib::EncryptedArrayBase::badDimensionAutomorphCorrection (
            Ctxt & ctxt,
            long i,
            long amt ) const  [pure virtual]
```

Correct an automorphism in a bad dimension.

Parameters

ctxt	Ctxt to perform the correction on.
i	Dimension of which to correct.
amt	Exponent of the automorphism.

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.3 buildLinPolyCoeffs()

```
virtual void helib::EncryptedArrayBase::buildLinPolyCoeffs (
            std::vector< NTL::ZZX > & C,
            const std::vector< NTL::ZZX > & L ) const  [pure virtual]
```

Linearized polynomials. L describes a linear map M by describing its action on the standard power basis: M(x^j mod G) = (L[j] mod G), for j = 0..d-1. The result is a coefficient std::vector C for the linearized polynomial representing M: a polynomial h in Z/(p^r)[X] of degree $<$ d is sent to.

$$//!M(h(X) \bmod G) = \sum_{i=0}^{d-1} (C[j] \cdot h(X^{p^j})) \bmod G).//!$$

Implemented in helib::EncryptedArrayDerived$<$ type $>$.

7.43.3.4 clone()

```
virtual EncryptedArrayBase* helib::EncryptedArrayBase::clone ( ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived$<$ type $>$.

7.43.3.5 coordinate()

```
long helib::EncryptedArrayBase::coordinate (
            long i,
            long k ) const  [inline]
```

returns coordinate of index k along the i'th dimension

7.43.3.6 decode() [1/3]

```
virtual void helib::EncryptedArrayBase::decode (
            PlaintextArray & array,
            const NTL::ZZX & ptxt ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayDerived$<$ type $>$.

7.43.3.7 decode() [2/3]

```
virtual void helib::EncryptedArrayBase::decode (
            std::vector< long > & array,
            const NTL::ZZX & ptxt ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayDerived$<$ type $>$.

7.43.3.8 decode() [3/3]

```
virtual void helib::EncryptedArrayBase::decode (
            std::vector< NTL::ZZX > & array,
            const NTL::ZZX & ptxt ) const [pure virtual]
```

Implemented in helib::EncryptedArrayDerived< type >.

7.43.3.9 decode1Slot() [1/2]

```
long helib::EncryptedArrayBase::decode1Slot (
            const NTL::ZZX & ptxt,
            long i ) const [inline]
```

7.43.3.10 decode1Slot() [2/2]

```
void helib::EncryptedArrayBase::decode1Slot (
            NTL::ZZX & slot,
            const NTL::ZZX & ptxt,
            long i ) const [inline]
```

7.43.3.11 decrypt() [1/5]

```
virtual void helib::EncryptedArrayBase::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            PlaintextArray & ptxt ) const [pure virtual]
```

Implemented in helib::EncryptedArrayDerived< type >.

7.43.3.12 decrypt() [2/5]

```
virtual void helib::EncryptedArrayBase::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            std::vector< cx_double > & ptxt ) const [pure virtual]
```

Implemented in helib::EncryptedArrayCx.

7.43.3.13 decrypt() [3/5]

```
virtual void helib::EncryptedArrayBase::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            std::vector< double > & ptxt ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayCx.

7.43.3.14 decrypt() [4/5]

```
virtual void helib::EncryptedArrayBase::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            std::vector< long > & ptxt ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayDerived< type >.

7.43.3.15 decrypt() [5/5]

```
virtual void helib::EncryptedArrayBase::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            std::vector< NTL::ZZX > & ptxt ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayDerived< type >.

7.43.3.16 decrypt1Slot() [1/2]

```
long helib::EncryptedArrayBase::decrypt1Slot (
            const Ctxt & ctxt,
            const SecKey & sKey,
            long i ) const  [inline]
```

7.43.3.17 decrypt1Slot() [2/2]

```
void helib::EncryptedArrayBase::decrypt1Slot (
            NTL::ZZX & slot,
            const Ctxt & ctxt,
            const SecKey & sKey,
            long i ) const  [inline]
```

7.43.3.18 dimension()

```
long helib::EncryptedArrayBase::dimension ( ) const  [inline]
```

Number of dimensions of hypercube.

7.43.3.19 encode() [1/7]

```
virtual void helib::EncryptedArrayBase::encode (
            NTL::ZZX & ptxt,
            const PlaintextArray & array ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayDerived< type >.

7.43.3.20 encode() [2/7]

```
virtual void helib::EncryptedArrayBase::encode (
            NTL::ZZX & ptxt,
            const std::vector< long > & array ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayDerived< type >.

7.43.3.21 encode() [3/7]

```
virtual void helib::EncryptedArrayBase::encode (
            NTL::ZZX & ptxt,
            const std::vector< NTL::ZZX > & array ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayDerived< type >.

7.43.3.22 encode() [4/7]

```
virtual void helib::EncryptedArrayBase::encode (
            zzX & ptxt,
            const PlaintextArray & array ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayDerived< type >.

7.43.3.23 encode() [5/7]

```
virtual void helib::EncryptedArrayBase::encode (
            zzX & ptxt,
            const std::vector< long > & array ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayDerived< type >.

7.43.3.24 encode() [6/7]

```
void helib::EncryptedArrayBase::encode (
            zzX & ptxt,
            const std::vector< NTL::ZZX > & array ) const  [inline]
```

7.43.3.25 encode() [7/7]

```
virtual void helib::EncryptedArrayBase::encode (
            zzX & ptxt,
            const std::vector< zzX > & array ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayDerived< type >.

7.43.3.26 encodeUnitSelector()

```
virtual void helib::EncryptedArrayBase::encodeUnitSelector (
            zzX & ptxt,
            long i ) const  [pure virtual]
```

Encodes a std::vector with 1 at position i and 0 everywhere else.

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.27 encrypt()

```
template<typename PTXT >
void helib::EncryptedArrayBase::encrypt (
            Ctxt & ctxt,
            const PubKey & key,
            const PTXT & ptxt ) const  [inline]
```

7.43.3.28 getContext()

```
virtual const Context& helib::EncryptedArrayBase::getContext ( ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.29 getDegree()

```
virtual long helib::EncryptedArrayBase::getDegree ( ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.30 getP2R()

```
virtual long helib::EncryptedArrayBase::getP2R ( ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.31 getPAlgebra()

```
virtual const PAlgebra& helib::EncryptedArrayBase::getPAlgebra ( ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.32 getTag()

```
virtual PA_tag helib::EncryptedArrayBase::getTag ( ) const  [pure virtual]
```

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.33 nativeDimension()

```
bool helib::EncryptedArrayBase::nativeDimension (
             long i ) const  [inline]
```

Is rotations in given dimension a "native" operation?

7.43.3.34 random() [1/2]

```
virtual void helib::EncryptedArrayBase::random (
            std::vector< long > & array ) const [pure virtual]
```

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.35 random() [2/2]

```
virtual void helib::EncryptedArrayBase::random (
            std::vector< NTL::ZZX > & array ) const [pure virtual]
```

Implemented in helib::EncryptedArrayDerived< type >.

7.43.3.36 restoreContext()

```
virtual void helib::EncryptedArrayBase::restoreContext ( ) const [inline], [virtual]
```

Reimplemented in helib::EncryptedArrayDerived< type >.

7.43.3.37 restoreContextForG()

```
virtual void helib::EncryptedArrayBase::restoreContextForG ( ) const [inline], [virtual]
```

Reimplemented in helib::EncryptedArrayDerived< type >.

7.43.3.38 rotate()

```
virtual void helib::EncryptedArrayBase::rotate (
            Ctxt & ctxt,
            long k ) const [pure virtual]
```

Right rotation as a linear array. E.g., rotating ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(n 1 2 ... n-1)

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.39 rotate1D() [1/2]

```
virtual void helib::EncryptedArrayBase::rotate1D (
            Ctxt & ctxt,
            long i,
            long k,
            bool dc = false ) const [pure virtual]
```

right-rotate k positions along the i'th dimension

Parameters

dc	means "don't care", which means that the caller guarantees that only zero elements rotate off the end – this allows for some optimizations that would not otherwise be possible

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.40 rotate1D() [2/2]

```
template<typename U >
void helib::EncryptedArrayBase::rotate1D (
            std::vector< U > & out,
            const std::vector< U > & in,
            long i,
            long offset ) const  [inline]
```

rotate an array by offset in the i'th dimension (output should not alias input)

7.43.3.41 shift()

```
virtual void helib::EncryptedArrayBase::shift (
            Ctxt & ctxt,
            long k ) const  [pure virtual]
```

Non-cyclic right shift with zero fill E.g., shifting ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(0 1 2... n-1)

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.42 shift1D()

```
virtual void helib::EncryptedArrayBase::shift1D (
            Ctxt & ctxt,
            long i,
            long k ) const  [pure virtual]
```

Right shift k positions along the i'th dimension with zero fill.

Implemented in helib::EncryptedArrayCx, and helib::EncryptedArrayDerived< type >.

7.43.3.43 size()

```
long helib::EncryptedArrayBase::size ( ) const  [inline]
```

Total size (# of slots) of hypercube.

7.43.3.44 sizeOfDimension()

```
long helib::EncryptedArrayBase::sizeOfDimension (
            long i ) const  [inline]
```

Size of given dimension.

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

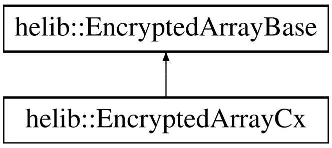
- /HElib/include/helib/EncryptedArray.h

7.44 helib::EncryptedArrayCx Class Reference

A different derived class to be used for the approximate-numbers scheme.

```
#include <EncryptedArray.h>
```

Inheritance diagram for helib::EncryptedArrayCx:



Public Member Functions

- double encodei (zzX &ptxt, long precision=-1) const
- EncryptedArrayCx (const Context &_context)
- EncryptedArrayCx (const Context &_context, const PAlgebraModCx &_alMod)
- EncryptedArrayBase ∗ clone () const override
- const zzX & getiEncoded () const
- PA_tag getTag () const override
- const Context & getContext () const override
- const PAlgebra & getPAlgebra () const override
- long getDegree () const override
- void rotate (Ctxt &ctxt, long k) const override

  Right rotation as a linear array. E.g., rotating ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(n 1 2 ... n-1)
- void shift (Ctxt &ctxt, long k) const override

  Non-cyclic right shift with zero fill E.g., shifting ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(0 1 2... n-1)
- void rotate1D (Ctxt &ctxt, long i, long k, bool dc=false) const override

  right-rotate k positions along the i'th dimension
- void shift1D (Ctxt &ctxt, long i, long k) const override

  Right shift k positions along the i'th dimension with zero fill.
- long getP2R () const override
- void encode (UNUSED zzX &ptxt, UNUSED const std::vector< long > &array) const override

  Unimplemented encode function for BGV. It will always throw helib::LogicError.
- void encode (UNUSED NTL::ZZX &ptxt, UNUSED const std::vector< long > &array) const override

  Unimplemented encode function for BGV. It will always throw helib::LogicError.
- void encode (UNUSED zzX &ptxt, UNUSED const std::vector< zzX > &array) const override

  Unimplemented encode function for BGV. It will always throw helib::LogicError.
- void encode (UNUSED zzX &ptxt, UNUSED const PlaintextArray &array) const override

  Unimplemented encode function for BGV. It will always throw helib::LogicError.
- void encode (UNUSED NTL::ZZX &ptxt, UNUSED const std::vector< NTL::ZZX > &array) const override

  Unimplemented encode function for BGV. It will always throw helib::LogicError.
- void encode (UNUSED NTL::ZZX &ptxt, UNUSED const PlaintextArray &array) const override

  Unimplemented encode function for BGV. It will always throw helib::LogicError.
- void decode (UNUSED std::vector< long > &array, UNUSED const NTL::ZZX &ptxt) const override

  Unimplemented decode function for BGV. It will always throw helib::LogicError.
- void decode (UNUSED std::vector< NTL::ZZX > &array, UNUSED const NTL::ZZX &ptxt) const override

  Unimplemented decode function for BGV. It will always throw helib::LogicError.
- void decode (UNUSED PlaintextArray &array, UNUSED const NTL::ZZX &ptxt) const override

Unimplemented decode function for BGV. It will always throw helib::LogicError.
- void random (UNUSED std::vector< NTL::ZZX > &array) const override

  Unimplemented random function for BGV. It will always throw helib::LogicError.
- void decrypt (UNUSED const Ctxt &ctxt, UNUSED const SecKey &sKey, UNUSED std::vector< long > &ptxt) const override

  Unimplemented decrypt function for BGV. It will always throw helib::LogicError.
- void decrypt (UNUSED const Ctxt &ctxt, UNUSED const SecKey &sKey, UNUSED std::vector< NTL::ZZX > &ptxt) const override

  Unimplemented decrypt function for BGV. It will always throw helib::LogicError.
- void decrypt (UNUSED const Ctxt &ctxt, UNUSED const SecKey &sKey, UNUSED PlaintextArray &ptxt) const override

  Unimplemented decrypt function for BGV. It will always throw helib::LogicError.
- void buildLinPolyCoeffs (UNUSED std::vector< NTL::ZZX > &C, UNUSED const std::vector< NTL::ZZX > &L) const override

  Unimplemented buildLinPolyCoeffs function for BGV. It will always throw helib::LogicError.
- double encode (zzX &ptxt, const std::vector< cx_double > &array, double useThisSize, long precision=-1) const
- double encode (zzX &ptxt, const std::vector< double > &array, double useThisSize, long precision=-1) const
- double encode (zzX &ptxt, const std::vector< long > &array, double useThisSize, long precision=-1) const
- template<typename Scheme >
  double encode (zzX &out, const Ptxt< Scheme > &ptxt, double useThisSize, long precision=-1) const

  Encode a `Ptxt` object into a `zzX`.
- double encode (zzX &ptxt, double aSingleNumber, double useThisSize=-1, long precision=-1) const
- template<typename PTXT >
  double encode (NTL::ZZX &ptxt, const PTXT &pt, double useThisSize=-1, long precision=-1) const
- void encryptOneNum (Ctxt &ctxt, const PubKey &key, double num, double useThisSize=-1, long precision=-1) const
- template<typename PTXT >
  void encrypt (Ctxt &ctxt, const PubKey &key, const PTXT &ptxt, double useThisSize, long precision=-1) const
- template<typename PTXT >
  void encrypt (Ctxt &ctxt, const PubKey &key, const PTXT &ptxt) const
- void encodeUnitSelector (zzX &ptxt, long i) const override

  Encodes a std::vector with 1 at position i and 0 everywhere else.
- double encodeRoundingError () const
- long encodeScalingFactor (long precision=-1, double roundErr=-1.0) const
- void decode (std::vector< cx_double > &array, const zzX &ptxt, double scaling) const
- void decode (std::vector< cx_double > &array, const NTL::ZZX &ptxt, double scaling) const
- void decode (std::vector< double > &array, const zzX &ptxt, double scaling) const
- void decode (std::vector< double > &array, const NTL::ZZX &ptxt, double scaling) const
- void random (std::vector< cx_double > &array, double rad=1.0) const
- void random (std::vector< double > &array, double rad=1.0) const
- void random (std::vector< long > &array) const override
- void decrypt (const Ctxt &ctxt, const SecKey &sKey, std::vector< cx_double > &ptxt) const override
- void decrypt (const Ctxt &ctxt, const SecKey &sKey, std::vector< double > &ptxt) const override
- template<typename Scheme >
  void decrypt (const Ctxt &ctxt, const SecKey &sKey, Ptxt< Scheme > &ptxt) const

  Decrypt ciphertext to a plaintext relative to a specific scheme.
- void extractRealPart (Ctxt &c) const
- template<typename Scheme >
  void extractRealPart (Ptxt< Scheme > &p) const

  Extract the real part of a `CKKS` plaintext.
- template<typename Scheme >
  void extractImPart (Ptxt< Scheme > &p) const

  Extract the imaginary part of a `CKKS` plaintext.

- void extractImPart (Ctxt &c, DoubleCRT *dcrt=nullptr) const
- void badDimensionAutomorphCorrection (Ctxt &ctxt, long i, long k) const override

  Correct an automorphism in a bad dimension.

Linearized polynomials for EncryptedArrayCx

*buildLinPolyCoeffs returns in C two encoded constants such that the linear transformation(s) defined as L(1) = oneImage and L(i)=iImage can be computed as: L(x) = C[0]*x + C[1]*conjugate(x). Once C is computed, we can apply this L to a ciphertext by calling applyLinPolyLL(ctxt, C, 2). Alternatively, we can convert C to a vector of two DoubleCRT objects, then call applyLinPolyLL(ctxt, dcrtVec, 2). This lets us compute the DoubleCRT object just once, then use them many times.*

- void buildLinPolyCoeffs (std::vector< zzX > &C, const cx_double &oneImage, const cx_double &iImage, long precision=0) const

  First variant: same linear transformation in all the slots.
- void buildLinPolyCoeffs (std::vector< zzX > &C, const std::vector< cx_double > &oneImages, const std::vector< cx_double > &iImages, long precision=0) const

  Second variant: different linear transformation in each slots.

Static Public Member Functions

- static double roundedSize (double x)
- static void convert (std::vector< cx_double > &out, const std::vector< double > &in)
- static void convert (std::vector< double > &out, const std::vector< cx_double > &in)
- static void convert (std::vector< cx_double > &out, const std::vector< long > &in)
- static void convert (std::vector< long > &out, const std::vector< cx_double > &in)

7.44.1 Detailed Description

A different derived class to be used for the approximate-numbers scheme.

7.44.2 Constructor & Destructor Documentation

7.44.2.1 EncryptedArrayCx() [1/2]

```
helib::EncryptedArrayCx::EncryptedArrayCx (
            const Context & _context )  [inline], [explicit]
```

7.44.2.2 EncryptedArrayCx() [2/2]

```
helib::EncryptedArrayCx::EncryptedArrayCx (
            const Context & _context,
            const PAlgebraModCx & _alMod )  [inline]
```

7.44.3 Member Function Documentation

7.44.3.1 badDimensionAutomorphCorrection()

```
void helib::EncryptedArrayCx::badDimensionAutomorphCorrection (
            Ctxt & ctxt,
            long i,
            long amt ) const [override], [virtual]
```

Correct an automorphism in a bad dimension.

Parameters

ctxt	Ctxt to perform the correction on.
i	Dimension of which to correct.
amt	Exponent of the automorphism.

Implements helib::EncryptedArrayBase.

7.44.3.2 buildLinPolyCoeffs() [1/3]

```
void helib::EncryptedArrayCx::buildLinPolyCoeffs (
            std::vector< zzX > & C,
            const cx_double & oneImage,
            const cx_double & iImage,
            long precision = 0 ) const
```

First variant: same linear transformation in all the slots.

7.44.3.3 buildLinPolyCoeffs() [2/3]

```
void helib::EncryptedArrayCx::buildLinPolyCoeffs (
            std::vector< zzX > & C,
            const std::vector< cx_double > & oneImages,
            const std::vector< cx_double > & iImages,
            long precision = 0 ) const
```

Second variant: different linear transformation in each slots.

7.44.3.4 buildLinPolyCoeffs() [3/3]

```
void helib::EncryptedArrayCx::buildLinPolyCoeffs (
            UNUSED std::vector< NTL::ZZX > & C,
            UNUSED const std::vector< NTL::ZZX > & L ) const [inline], [override]
```

Unimplemented buildLinPolyCoeffs function for BGV. It will always throw helib::LogicError.

Parameters

C	Unused.
L	Unused.

7.44.3.5 clone()

```
EncryptedArrayBase* helib::EncryptedArrayCx::clone ( ) const [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.44.3.6 convert() [1/4]

```
static void helib::EncryptedArrayCx::convert (
            std::vector< cx_double > & out,
            const std::vector< double > & in ) [inline], [static]
```

7.44.3.7 convert() [2/4]

```
static void helib::EncryptedArrayCx::convert (
            std::vector< cx_double > & out,
            const std::vector< long > & in ) [inline], [static]
```

7.44.3.8 convert() [3/4]

```
static void helib::EncryptedArrayCx::convert (
            std::vector< double > & out,
            const std::vector< cx_double > & in ) [inline], [static]
```

7.44.3.9 convert() [4/4]

```
static void helib::EncryptedArrayCx::convert (
            std::vector< long > & out,
            const std::vector< cx_double > & in ) [inline], [static]
```

7.44.3.10 decode() [1/7]

```
void helib::EncryptedArrayCx::decode (
            std::vector< cx_double > & array,
            const NTL::ZZX & ptxt,
            double scaling ) const [inline]
```

7.44.3.11 decode() [2/7]

```
void helib::EncryptedArrayCx::decode (
            std::vector< cx_double > & array,
            const zzX & ptxt,
            double scaling ) const
```

7.44.3.12 decode() [3/7]

```
void helib::EncryptedArrayCx::decode (
            std::vector< double > & array,
            const NTL::ZZX & ptxt,
            double scaling ) const [inline]
```

7.44.3.13 decode() [4/7]

```
void helib::EncryptedArrayCx::decode (
            std::vector< double > & array,
            const zzX & ptxt,
            double scaling ) const [inline]
```

7.44.3.14 decode() [5/7]

```
void helib::EncryptedArrayCx::decode (
            UNUSED PlaintextArray & array,
            UNUSED const NTL::ZZX & ptxt ) const [inline], [override]
```

Unimplemented decode function for BGV. It will always throw helib::LogicError.

Parameters

array	Unused.
ptxt	Unused.

7.44.3.15 decode() [6/7]

```
void helib::EncryptedArrayCx::decode (
            UNUSED std::vector< long > & array,
            UNUSED const NTL::ZZX & ptxt ) const  [inline], [override]
```

Unimplemented decode function for BGV. It will always throw helib::LogicError.

Parameters

array	Unused.
ptxt	Unused.

7.44.3.16 decode() [7/7]

```
void helib::EncryptedArrayCx::decode (
            UNUSED std::vector< NTL::ZZX > & array,
            UNUSED const NTL::ZZX & ptxt ) const  [inline], [override]
```

Unimplemented decode function for BGV. It will always throw helib::LogicError.

Parameters

array	Unused.
ptxt	Unused.

7.44.3.17 decrypt() [1/6]

```
template<typename Scheme >
void helib::EncryptedArrayCx::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            Ptxt< Scheme > & ptxt ) const  [inline]
```

Decrypt ciphertext to a plaintext relative to a specific scheme.

Template Parameters

Scheme	Encryption scheme to be used (either BGV or CKKS).

Parameters

ctxt	Ciphertext to decrypt.
sKey	Secret key to be used for decryption.
ptxt	Plaintext into which to decrypt. Decrypt a Ctxt ciphertext object to a Ptxt plaintext one relative to a specific scheme.

7.44.3.18 decrypt() [2/6]

```
void helib::EncryptedArrayCx::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            std::vector< cx_double > & ptxt ) const  [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.44.3.19 decrypt() [3/6]

```
void helib::EncryptedArrayCx::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            std::vector< double > & ptxt ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.44.3.20 decrypt() [4/6]

```
void helib::EncryptedArrayCx::decrypt (
            UNUSED const Ctxt & ctxt,
            UNUSED const SecKey & sKey,
            UNUSED PlaintextArray & ptxt ) const  [inline], [override]
```

Unimplemented decrypt function for BGV. It will always throw helib::LogicError.

Parameters

ctxt	Unused.
sKey	Unused.
ptxt	Unused.

7.44.3.21 decrypt() [5/6]

```
void helib::EncryptedArrayCx::decrypt (
            UNUSED const Ctxt & ctxt,
            UNUSED const SecKey & sKey,
            UNUSED std::vector< long > & ptxt ) const  [inline], [override]
```

Unimplemented decrypt function for BGV. It will always throw helib::LogicError.

Parameters

ctxt	Unused.
sKey	Unused.
ptxt	Unused.

7.44.3.22 decrypt() [6/6]

```
void helib::EncryptedArrayCx::decrypt (
            UNUSED const Ctxt & ctxt,
            UNUSED const SecKey & sKey,
            UNUSED std::vector< NTL::ZZX > & ptxt ) const  [inline], [override]
```

Unimplemented decrypt function for BGV. It will always throw helib::LogicError.

Parameters

ctxt	Unused.
sKey	Unused.
ptxt	Unused.

7.44.3.23 encode() [1/12]

```
template<typename PTXT >
double helib::EncryptedArrayCx::encode (
            NTL::ZZX & ptxt,
            const PTXT & pt,
            double useThisSize = -1,
            long precision = -1 ) const [inline]
```

7.44.3.24 encode() [2/12]

```
void helib::EncryptedArrayCx::encode (
            UNUSED NTL::ZZX & ptxt,
            UNUSED const PlaintextArray & array ) const [inline], [override]
```

Unimplemented encode function for BGV. It will always throw helib::LogicError.

Parameters

ptxt	Unused.
array	Unused.

7.44.3.25 encode() [3/12]

```
void helib::EncryptedArrayCx::encode (
            UNUSED NTL::ZZX & ptxt,
            UNUSED const std::vector< long > & array ) const [inline], [override]
```

Unimplemented encode function for BGV. It will always throw helib::LogicError.

Parameters

ptxt	Unused.
array	Unused.

7.44.3.26 encode() [4/12]

```
void helib::EncryptedArrayCx::encode (
            UNUSED NTL::ZZX & ptxt,
            UNUSED const std::vector< NTL::ZZX > & array ) const [inline], [override]
```

Unimplemented encode function for BGV. It will always throw helib::LogicError.

Parameters

ptxt	Unused.
array	Unused.

7.44.3.27 encode() [5/12]

```
void helib::EncryptedArrayCx::encode (
            UNUSED zzX & ptxt,
            UNUSED const PlaintextArray & array ) const  [inline], [override]
```

Unimplemented encode function for BGV. It will always throw helib::LogicError.

Parameters

ptxt	Unused.
array	Unused.

7.44.3.28 encode() [6/12]

```
void helib::EncryptedArrayCx::encode (
            UNUSED zzX & ptxt,
            UNUSED const std::vector< long > & array ) const  [inline], [override]
```

Unimplemented encode function for BGV. It will always throw helib::LogicError.

Parameters

ptxt	Unused.
array	Unused.

7.44.3.29 encode() [7/12]

```
void helib::EncryptedArrayCx::encode (
            UNUSED zzX & ptxt,
            UNUSED const std::vector< zzX > & array ) const  [inline], [override]
```

Unimplemented encode function for BGV. It will always throw helib::LogicError.

Parameters

ptxt	Unused.
array	Unused.

7.44.3.30 encode() [8/12]

```
template<typename Scheme >
double helib::EncryptedArrayCx::encode (
            zzX & out,
            const Ptxt< Scheme > & ptxt,
            double useThisSize,
            long precision = -1 ) const  [inline]
```

Encode a `Ptxt` object into a `zzX`.

Template Parameters

Scheme	Encryption scheme to be used (either `BGV` or `CKKS`).

Parameters

out	Polynomial to encode into.
ptxt	Plaintext `Ptxt` object to encode.
useThisSize	Size to use.
precision	Precision to use.

Returns

The scaling factor used in the encoding routine.

7.44.3.31 encode() [9/12]

```
double helib::EncryptedArrayCx::encode (
            zzX & ptxt,
            const std::vector< cx_double > & array,
            double useThisSize,
            long precision = -1 ) const
```

7.44.3.32 encode() [10/12]

```
double helib::EncryptedArrayCx::encode (
            zzX & ptxt,
            const std::vector< double > & array,
            double useThisSize,
            long precision = -1 ) const [inline]
```

7.44.3.33 encode() [11/12]

```
double helib::EncryptedArrayCx::encode (
            zzX & ptxt,
            const std::vector< long > & array,
            double useThisSize,
            long precision = -1 ) const [inline]
```

7.44.3.34 encode() [12/12]

```
double helib::EncryptedArrayCx::encode (
            zzX & ptxt,
            double aSingleNumber,
            double useThisSize = -1,
            long precision = -1 ) const
```

7.44.3.35 encodei()

```
double helib::EncryptedArrayCx::encodei (
            zzX & ptxt,
            long precision = -1 ) const
```

7.44.3.36 encodeRoundingError()

```
double helib::EncryptedArrayCx::encodeRoundingError ( ) const [inline]
```

7.44.3.37 encodeScalingFactor()

```
long helib::EncryptedArrayCx::encodeScalingFactor (
            long precision = -1,
            double roundErr = -1.0 ) const [inline]
```

7.44.3.38 encodeUnitSelector()

```
void helib::EncryptedArrayCx::encodeUnitSelector (
            zzX & ptxt,
            long i ) const  [inline], [override], [virtual]
```

Encodes a std::vector with 1 at position i and 0 everywhere else.

Implements helib::EncryptedArrayBase.

7.44.3.39 encrypt() [1/2]

```
template<typename PTXT >
void helib::EncryptedArrayCx::encrypt (
            Ctxt & ctxt,
            const PubKey & key,
            const PTXT & ptxt ) const  [inline]
```

7.44.3.40 encrypt() [2/2]

```
template<typename PTXT >
void helib::EncryptedArrayCx::encrypt (
            Ctxt & ctxt,
            const PubKey & key,
            const PTXT & ptxt,
            double useThisSize,
            long precision = -1 ) const  [inline]
```

7.44.3.41 encryptOneNum()

```
void helib::EncryptedArrayCx::encryptOneNum (
            Ctxt & ctxt,
            const PubKey & key,
            double num,
            double useThisSize = -1,
            long precision = -1 ) const  [inline]
```

7.44.3.42 extractImPart() [1/2]

```
void helib::EncryptedArrayCx::extractImPart (
            Ctxt & c,
            DoubleCRT * dcrt = nullptr ) const
```

Note: If called with dcrt==nullptr, extractImPart will perform FFT's when encoding i as a DoubleCRT object. If called with dcrt!=nullptr, it assumes that dcrt points to an object that encodes i.

7.44.3.43 extractImPart() [2/2]

```
template<typename Scheme >
void helib::EncryptedArrayCx::extractImPart (
            Ptxt< Scheme > & p ) const  [inline]
```

Extract the imaginary part of a CKKS plaintext.

Template Parameters

Scheme	Encryption scheme to be used (must be CKKS).

Parameters

p	Plaintext on which to operate.

7.44.3.44 extractRealPart() [1/2]

```
void helib::EncryptedArrayCx::extractRealPart (
            Ctxt & c ) const
```

7.44.3.45 extractRealPart() [2/2]

```
template<typename Scheme >
void helib::EncryptedArrayCx::extractRealPart (
            Ptxt< Scheme > & p ) const [inline]
```

Extract the real part of a CKKS plaintext.

Template Parameters

Scheme	Encryption scheme to be used (must be CKKS).

Parameters

p	Plaintext on which to operate.

7.44.3.46 getContext()

```
const Context& helib::EncryptedArrayCx::getContext ( ) const [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.44.3.47 getDegree()

```
long helib::EncryptedArrayCx::getDegree ( ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.44.3.48 getiEncoded()

```
const zzX & helib::EncryptedArrayCx::getiEncoded ( ) const
```

7.44.3.49 getP2R()

```
long helib::EncryptedArrayCx::getP2R ( ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.44.3.50 getPAlgebra()

```
const PAlgebra& helib::EncryptedArrayCx::getPAlgebra ( ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.44.3.51 getTag()

```
PA_tag helib::EncryptedArrayCx::getTag ( ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.44.3.52 random() [1/4]

```
void helib::EncryptedArrayCx::random (
            std::vector< cx_double > & array,
            double rad = 1.0 ) const
```

7.44.3.53 random() [2/4]

```
void helib::EncryptedArrayCx::random (
            std::vector< double > & array,
            double rad = 1.0 ) const [inline]
```

7.44.3.54 random() [3/4]

```
void helib::EncryptedArrayCx::random (
            std::vector< long > & array ) const [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.44.3.55 random() [4/4]

```
void helib::EncryptedArrayCx::random (
            UNUSED std::vector< NTL::ZZX > & array ) const [inline], [override]
```

Unimplemented random function for BGV. It will always throw helib::LogicError.

Parameters

array	Unused.

7.44.3.56 rotate()

```
void helib::EncryptedArrayCx::rotate (
            Ctxt & ctxt,
            long k ) const [override], [virtual]
```

Right rotation as a linear array. E.g., rotating ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(n 1 2 ... n-1)

Implements helib::EncryptedArrayBase.

7.44.3.57 rotate1D()

```
void helib::EncryptedArrayCx::rotate1D (
            Ctxt & ctxt,
            long i,
            long k,
            bool dc = false ) const [override], [virtual]
```

right-rotate k positions along the i'th dimension

Parameters

dc	means "don't care", which means that the caller guarantees that only zero elements rotate off the end – this allows for some optimizations that would not otherwise be possible

Implements helib::EncryptedArrayBase.

7.44.3.58 roundedSize()

```
static double helib::EncryptedArrayCx::roundedSize (
            double x )  [inline], [static]
```

7.44.3.59 shift()

```
void helib::EncryptedArrayCx::shift (
            Ctxt & ctxt,
            long k ) const  [override], [virtual]
```

Non-cyclic right shift with zero fill E.g., shifting ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(0 1 2... n-1)

Implements helib::EncryptedArrayBase.

7.44.3.60 shift1D()

```
void helib::EncryptedArrayCx::shift1D (
            Ctxt & ctxt,
            long i,
            long k ) const [override], [virtual]
```

Right shift k positions along the i'th dimension with zero fill.

Implements helib::EncryptedArrayBase.

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

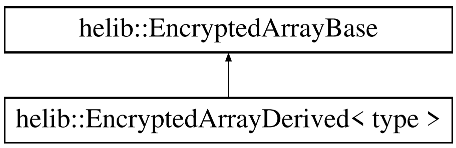
- /HElib/include/helib/EncryptedArray.h
- /HElib/src/EaCx.cpp

7.45 helib::EncryptedArrayDerived< type > Class Template Reference

Derived concrete implementation of EncryptedArrayBase.

```
#include <EncryptedArray.h>
```

Inheritance diagram for helib::EncryptedArrayDerived< type >:



Public Member Functions

- EncryptedArrayDerived (const Context &_context, const RX &_G, const PAlgebraMod &_tab)
- EncryptedArrayDerived (const EncryptedArrayDerived &other)
- EncryptedArrayDerived & operator= (const EncryptedArrayDerived &other)
- virtual EncryptedArrayBase * clone () const override
- virtual PA_tag getTag () const override
- template< template< typename > class T, typename... Args >
  void dispatch (Args &&... args) const
- const RX & getG () const
- const NTL::Mat< R > & getNormalBasisMatrix () const
- const NTL::Mat< R > & getNormalBasisMatrixInverse () const
- void initNormalBasisMatrix () const
- virtual void restoreContext () const override
- virtual void restoreContextForG () const override
- virtual const Context & getContext () const override
- virtual const PAlgebra & getPAlgebra () const override
- virtual long getDegree () const override
- const PAlgebraModDerived< type > & getTab () const
- virtual void rotate (Ctxt &ctxt, long k) const override

  Right rotation as a linear array. E.g., rotating ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(n 1 2 ... n-1)

- virtual void shift (Ctxt &ctxt, long k) const override

    Non-cyclic right shift with zero fill E.g., shifting ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(0 1 2... n-1)
- virtual void rotate1D (Ctxt &ctxt, long i, long k, bool dc=false) const override

    right-rotate k positions along the i'th dimension
- virtual void badDimensionAutomorphCorrection (Ctxt &ctxt, long i, long k) const override

    Correct an automorphism in a bad dimension.
- long getP2R () const override
- template<typename U >
  void rotate1D (std::vector< U > &out, const std::vector< U > &in, long i, long offset) const
- virtual void shift1D (Ctxt &ctxt, long i, long k) const override

    Right shift k positions along the i'th dimension with zero fill.
- void decrypt (UNUSED const Ctxt &ctxt, UNUSED const SecKey &sKey, UNUSED std::vector< double > &ptxt) const override

    Unimplemented decrypt function for CKKS. It will always throw helib::LogicError.
- void decrypt (UNUSED const Ctxt &ctxt, UNUSED const SecKey &sKey, UNUSED std::vector< cx_double > &ptxt) const override

    Unimplemented decrypt function for CKKS. It will always throw helib::LogicError.
- virtual void encode (NTL::ZZX &ptxt, const std::vector< long > &array) const override
- virtual void encode (zzX &ptxt, const std::vector< long > &array) const override
- virtual void encode (NTL::ZZX &ptxt, const std::vector< NTL::ZZX > &array) const override
- virtual void encode (zzX &ptxt, const std::vector< zzX > &array) const override
- virtual void encode (NTL::ZZX &ptxt, const PlaintextArray &array) const override
- virtual void encode (zzX &ptxt, const PlaintextArray &array) const override
- virtual void encodeUnitSelector (zzX &ptxt, long i) const override

    Encodes a std::vector with 1 at position i and 0 everywhere else.
- virtual void decode (std::vector< long > &array, const NTL::ZZX &ptxt) const override
- virtual void decode (std::vector< NTL::ZZX > &array, const NTL::ZZX &ptxt) const override
- virtual void decode (PlaintextArray &array, const NTL::ZZX &ptxt) const override
- virtual void decode (PlaintextArray &array, const zzX &ptxt) const
- virtual void random (std::vector< long > &array) const override
- virtual void random (std::vector< NTL::ZZX > &array) const override
- virtual void decrypt (const Ctxt &ctxt, const SecKey &sKey, std::vector< long > &ptxt) const override
- virtual void decrypt (const Ctxt &ctxt, const SecKey &sKey, std::vector< NTL::ZZX > &ptxt) const override
- virtual void decrypt (const Ctxt &ctxt, const SecKey &sKey, PlaintextArray &ptxt) const override
- virtual void buildLinPolyCoeffs (std::vector< NTL::ZZX > &C, const std::vector< NTL::ZZX > &L) const override

    Linearized polynomials. L describes a linear map M by describing its action on the standard power basis: M(x^j mod G) = (L[j] mod G), for j = 0..d-1. The result is a coefficient std::vector C for the linearized polynomial representing M: a polynomial h in Z/(p^r)[X] of degree < d is sent to.
- void encode (zzX &ptxt, const std::vector< RX > &array) const
- void decode (std::vector< RX > &array, const zzX &ptxt) const
- void encode (NTL::ZZX &ptxt, const std::vector< RX > &array) const
- void decode (std::vector< RX > &array, const NTL::ZZX &ptxt) const
- void encode (RX &ptxt, const std::vector< RX > &array) const
- void decode (std::vector< RX > &array, const RX &ptxt) const
- void random (std::vector< RX > &array) const
- void decrypt (const Ctxt &ctxt, const SecKey &sKey, std::vector< RX > &ptxt) const
- virtual void buildLinPolyCoeffs (std::vector< RX > &C, const std::vector< RX > &L) const

7.45.1 Detailed Description

template<typename type>
class helib::EncryptedArrayDerived< type >

Derived concrete implementation of EncryptedArrayBase.

7.45.2 Constructor & Destructor Documentation

7.45.2.1 EncryptedArrayDerived() [1/2]

```
template<typename type >
helib::EncryptedArrayDerived< type >::EncryptedArrayDerived (
            const Context & _context,
            const RX & _G,
            const PAlgebraMod & _tab )  [explicit]
```

7.45.2.2 EncryptedArrayDerived() [2/2]

```
template<typename type >
helib::EncryptedArrayDerived< type >::EncryptedArrayDerived (
            const EncryptedArrayDerived< type > & other )  [inline]
```

7.45.3 Member Function Documentation

7.45.3.1 badDimensionAutomorphCorrection()

```
template<typename type >
void helib::EncryptedArrayDerived< type >::badDimensionAutomorphCorrection (
            Ctxt & ctxt,
            long i,
            long amt ) const  [override], [virtual]
```

Correct an automorphism in a bad dimension.

Parameters

ctxt	Ctxt to perform the correction on.
i	Dimension of which to correct.
amt	Exponent of the automorphism.

Implements helib::EncryptedArrayBase.

7.45.3.2 buildLinPolyCoeffs() [1/2]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::buildLinPolyCoeffs (
            std::vector< NTL::ZZX > & C,
            const std::vector< NTL::ZZX > & L ) const  [override], [virtual]
```

Linearized polynomials. L describes a linear map M by describing its action on the standard power basis: M(x^j mod G) = (L[j] mod G), for j = 0..d-1. The result is a coefficient std::vector C for the linearized polynomial representing M: a polynomial h in Z/(p^r)[X] of degree < d is sent to.

$$//!M(h(X) \bmod G) = \sum_{i=0}^{d-1} (C[j] \cdot h(X^{p^j})) \bmod G).//!$$

Implements helib::EncryptedArrayBase.

7.45.3.3 buildLinPolyCoeffs() [2/2]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::buildLinPolyCoeffs (
            std::vector< RX > & C,
            const std::vector< RX > & L ) const  [virtual]
```

7.45.3.4 clone()

```
template<typename type >
virtual EncryptedArrayBase* helib::EncryptedArrayDerived< type >::clone ( ) const  [inline],
[override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.5 decode() [1/7]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::decode (
            PlaintextArray & array,
            const NTL::ZZX & ptxt ) const  [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.6 decode() [2/7]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::decode (
            PlaintextArray & array,
            const zzX & ptxt ) const [virtual]
```

7.45.3.7 decode() [3/7]

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::decode (
            std::vector< long > & array,
            const NTL::ZZX & ptxt ) const [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.8 decode() [4/7]

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::decode (
            std::vector< NTL::ZZX > & array,
            const NTL::ZZX & ptxt ) const [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.9 decode() [5/7]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::decode (
            std::vector< RX > & array,
            const NTL::ZZX & ptxt ) const
```

7.45.3.10 decode() [6/7]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::decode (
            std::vector< RX > & array,
            const RX & ptxt ) const
```

7.45.3.11 decode() [7/7]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::decode (
            std::vector< RX > & array,
            const zzX & ptxt ) const
```

7.45.3.12 decrypt() [1/6]

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            PlaintextArray & ptxt ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.13 decrypt() [2/6]

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            std::vector< long > & ptxt ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.14 decrypt() [3/6]

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            std::vector< NTL::ZZX > & ptxt ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.15 decrypt() [4/6]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::decrypt (
            const Ctxt & ctxt,
            const SecKey & sKey,
            std::vector< RX > & ptxt ) const  [inline]
```

7.45.3.16 decrypt() [5/6]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::decrypt (
            UNUSED const Ctxt & ctxt,
            UNUSED const SecKey & sKey,
            UNUSED std::vector< cx_double > & ptxt ) const  [inline], [override]
```

Unimplemented decrypt function for CKKS. It will always throw helib::LogicError.

Parameters

ctxt	Unused.
sKey	Unused.
ptxt	Unused.

7.45.3.17 decrypt() [6/6]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::decrypt (
            UNUSED const Ctxt & ctxt,
            UNUSED const SecKey & sKey,
            UNUSED std::vector< double > & ptxt ) const  [inline], [override]
```

Unimplemented decrypt function for CKKS. It will always throw helib::LogicError.

Parameters

ctxt	Unused.
sKey	Unused.
ptxt	Unused.

7.45.3.18 dispatch()

```
template<typename type >
template<template< typename > class T, typename...  Args>
void helib::EncryptedArrayDerived< type >::dispatch (
            Args &&...  args ) const  [inline]
```

7.45.3.19 encode() [1/9]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::encode (
            NTL::ZZX & ptxt,
            const PlaintextArray & array ) const  [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.20 encode() [2/9]

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::encode (
            NTL::ZZX & ptxt,
            const std::vector< long > & array ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.21 encode() [3/9]

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::encode (
            NTL::ZZX & ptxt,
            const std::vector< NTL::ZZX > & array ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.22 encode() [4/9]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::encode (
            NTL::ZZX & ptxt,
            const std::vector< RX > & array ) const
```

7.45.3.23 encode() [5/9]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::encode (
            RX & ptxt,
            const std::vector< RX > & array ) const
```

7.45.3.24 encode() [6/9]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::encode (
            zzX & ptxt,
            const PlaintextArray & array ) const  [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.25 encode() [7/9]

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::encode (
            zzX & ptxt,
            const std::vector< long > & array ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.26 encode() [8/9]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::encode (
            zzX & ptxt,
            const std::vector< RX > & array ) const
```

7.45.3.27 encode() [9/9]

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::encode (
            zzX & ptxt,
            const std::vector< zzX > & array ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.28 encodeUnitSelector()

```
template<typename type >
void helib::EncryptedArrayDerived< type >::encodeUnitSelector (
            zzX & ptxt,
            long i ) const  [override], [virtual]
```

Encodes a std::vector with 1 at position i and 0 everywhere else.

Implements helib::EncryptedArrayBase.

7.45.3.29 getContext()

```
template<typename type >
virtual const Context& helib::EncryptedArrayDerived< type >::getContext ( ) const  [inline],
[override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.30 getDegree()

```
template<typename type >
virtual long helib::EncryptedArrayDerived< type >::getDegree ( ) const [inline], [override],
[virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.31 getG()

```
template<typename type >
const RX& helib::EncryptedArrayDerived< type >::getG ( ) const [inline]
```

7.45.3.32 getNormalBasisMatrix()

```
template<typename type >
const NTL::Mat<R>& helib::EncryptedArrayDerived< type >::getNormalBasisMatrix ( ) const [inline]
```

7.45.3.33 getNormalBasisMatrixInverse()

```
template<typename type >
const NTL::Mat<R>& helib::EncryptedArrayDerived< type >::getNormalBasisMatrixInverse ( )
const [inline]
```

7.45.3.34 getP2R()

```
template<typename type >
long helib::EncryptedArrayDerived< type >::getP2R ( ) const [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.35 getPAlgebra()

```
template<typename type >
virtual const PAlgebra& helib::EncryptedArrayDerived< type >::getPAlgebra ( ) const [inline],
[override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.36 getTab()

```
template<typename type >
const PAlgebraModDerived<type>& helib::EncryptedArrayDerived< type >::getTab ( ) const  [inline]
```

7.45.3.37 getTag()

```
template<typename type >
virtual PA_tag helib::EncryptedArrayDerived< type >::getTag ( ) const  [inline], [override],
[virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.38 initNormalBasisMatrix()

```
template<typename type >
void helib::EncryptedArrayDerived< type >::initNormalBasisMatrix
```

7.45.3.39 operator=()

```
template<typename type >
EncryptedArrayDerived& helib::EncryptedArrayDerived< type >::operator= (
            const EncryptedArrayDerived< type > & other )  [inline]
```

7.45.3.40 random() [1/3]

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::random (
            std::vector< long > & array ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.41 random() [2/3]

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::random (
            std::vector< NTL::ZZX > & array ) const  [inline], [override], [virtual]
```

Implements helib::EncryptedArrayBase.

7.45.3.42 random() [3/3]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::random (
            std::vector< RX > & array ) const  [inline]
```

7.45.3.43 restoreContext()

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::restoreContext ( ) const  [inline], [override],
[virtual]
```

Reimplemented from helib::EncryptedArrayBase.

7.45.3.44 restoreContextForG()

```
template<typename type >
virtual void helib::EncryptedArrayDerived< type >::restoreContextForG ( ) const  [inline],
[override], [virtual]
```

Reimplemented from helib::EncryptedArrayBase.

7.45.3.45 rotate()

```
template<typename type >
void helib::EncryptedArrayDerived< type >::rotate (
            Ctxt & ctxt,
            long k ) const  [override], [virtual]
```

Right rotation as a linear array. E.g., rotating ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(n 1 2 ... n-1)

Implements helib::EncryptedArrayBase.

7.45.3.46 rotate1D() [1/2]

```
template<typename type >
void helib::EncryptedArrayDerived< type >::rotate1D (
            Ctxt & ctxt,
            long i,
            long k,
            bool dc = false ) const  [override], [virtual]
```

right-rotate k positions along the i'th dimension

Parameters

dc	means "don't care", which means that the caller guarantees that only zero elements rotate off the end – this allows for some optimizations that would not otherwise be possible

Implements helib::EncryptedArrayBase.

7.45.3.47 rotate1D() [2/2]

```
template<typename type >
template<typename U >
void helib::EncryptedArrayDerived< type >::rotate1D (
            std::vector< U > & out,
            const std::vector< U > & in,
            long i,
            long offset ) const [inline]
```

7.45.3.48 shift()

```
template<typename type >
void helib::EncryptedArrayDerived< type >::shift (
            Ctxt & ctxt,
            long k ) const  [override], [virtual]
```

Non-cyclic right shift with zero fill E.g., shifting ctxt=Enc(1 2 3 ... n) by k=1 gives Enc(0 1 2... n-1)

Implements helib::EncryptedArrayBase.

7.45.3.49 shift1D()

```
template<typename type >
void helib::EncryptedArrayDerived< type >::shift1D (
            Ctxt & ctxt,
            long i,
            long k ) const  [override], [virtual]
```

Right shift k positions along the i'th dimension with zero fill.

Implements helib::EncryptedArrayBase.

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

- /HElib/include/helib/EncryptedArray.h
- /HElib/src/EncryptedArray.cpp

7.46 helib::equals_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, bool &res, const PlaintextArray &pa, const PlaintextArray &other)
- static void apply (const EncryptedArrayDerived< type > &ea, bool &res, const PlaintextArray &pa, const std::vector< long > &other)
- static void apply (const EncryptedArrayDerived< type > &ea, bool &res, const PlaintextArray &pa, const std::vector< NTL::ZZX > &other)

7.46.1 Member Function Documentation

7.46.1.1 apply() [1/3]

```
template<typename type >
static void helib::equals_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            bool & res,
            const PlaintextArray & pa,
            const PlaintextArray & other ) [inline], [static]
```

7.46.1.2 apply() [2/3]

```
template<typename type >
static void helib::equals_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            bool & res,
            const PlaintextArray & pa,
            const std::vector< long > & other ) [inline], [static]
```

7.46.1.3 apply() [3/3]

```
template<typename type >
static void helib::equals_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            bool & res,
            const PlaintextArray & pa,
            const std::vector< NTL::ZZX > & other ) [inline], [static]
```

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

- /HElib/src/EncryptedArray.cpp

7.47 helib::EvalMap Class Reference

Class that provides the functionality for the linear transforms used in boostrapping. The constructor is invoked with three arguments:

`#include <EvalMap.h>`

Public Member Functions

- EvalMap (const EncryptedArray &_ea, bool minimal, const NTL::Vec< long > &mvec, bool _invert, bool build_cache, bool normal_basis=true)
- void upgrade ()
- void apply (Ctxt &ctxt) const

7.47.1 Detailed Description

Class that provides the functionality for the linear transforms used in boostrapping. The constructor is invoked with three arguments:

- an EncryptedArray object ea
- an integer vector mvec
- a boolean flag invert The mvec vector specifies the factorization of m to use in the "powerful basis" decomposition.

If the invert flag is false, the forward transformation is used. This transformation views the slots as being packed with powerful-basis coefficients and performs a multi-point polynomial evaluation. This is the second transformation used in bootstrapping.

If invert flag is true, the inverse transformation is used. In addition, the current implementation folds into the inverse transformation a transformation that moves the coefficients in each slot into a normal-basis representation, which helps with the unpacking procedure.

The constructor precomputes certain values, and the linear transformation itself is effected using the apply method.

Note that the factorization in mvec must correspond to the generators used in PAlgebra. The best way to ensure this is to directly use the output of the program in params.cpp: that program computes values for mvec (to be used here), and gens and ords (to be used in initialization of the Context).

7.47.2 Constructor & Destructor Documentation

7.47.2.1 EvalMap()

```
helib::EvalMap::EvalMap (
            const EncryptedArray & _ea,
            bool minimal,
            const NTL::Vec< long > & mvec,
            bool _invert,
            bool build_cache,
            bool normal_basis = true )
```

7.47.3 Member Function Documentation

7.47.3.1 apply()

```
void helib::EvalMap::apply (
            Ctxt & ctxt ) const
```

7.47.3.2 upgrade()

```
void helib::EvalMap::upgrade ( )
```

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

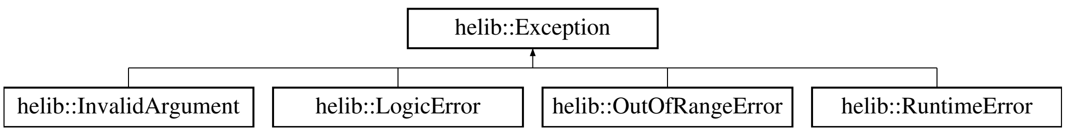
- /HElib/include/helib/EvalMap.h
- /HElib/src/EvalMap.cpp

7.48 helib::Exception Class Reference

Base class that other HElib exception classes inherit from.

```
#include <exceptions.h>
```

Inheritance diagram for helib::Exception:



Public Member Functions

- virtual ∼Exception ()=default
- virtual const char ∗ what () const noexcept=0

Protected Member Functions

- Exception ()=default

7.48.1 Detailed Description

Base class that other HElib exception classes inherit from.

7.48.2 Constructor & Destructor Documentation

7.48.2.1 ∼Exception()

```
virtual helib::Exception::~Exception ( ) [virtual], [default]
```

7.48.2.2 Exception()

```
helib::Exception::Exception ( )  [protected], [default]
```

7.48.3 Member Function Documentation

7.48.3.1 what()

```
virtual const char* helib::Exception::what ( ) const  [pure virtual], [noexcept]
```

Implemented in helib::InvalidArgument, helib::RuntimeError, helib::OutOfRangeError, and helib::LogicError.

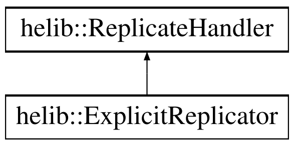
The documentation for this class was generated from the following file:

- /HElib/include/helib/exceptions.h

7.49 helib::ExplicitReplicator Class Reference

An implementation of ReplicateHandler that explicitly returns all the replicated ciphertexts in one big vector.

Inheritance diagram for helib::ExplicitReplicator:



Public Member Functions

- ExplicitReplicator (std::vector< Ctxt > &_v)
- virtual void handle (const Ctxt &ctxt)

7.49.1 Detailed Description

An implementation of ReplicateHandler that explicitly returns all the replicated ciphertexts in one big vector.

This is useful mostly for debugging purposes, for real parameters it would take a lot of memory.

7.49.2 Constructor & Destructor Documentation

7.49.2.1 ExplicitReplicator()

```
helib::ExplicitReplicator::ExplicitReplicator (
            std::vector< Ctxt > & _v ) [inline]
```

7.49.3 Member Function Documentation

7.49.3.1 handle()

```
virtual void helib::ExplicitReplicator::handle (
            const Ctxt & ctxt ) [inline], [virtual]
```

Implements helib::ReplicateHandler.

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

- /HElib/src/replicate.cpp

7.50 helib::fhe_stats_record Struct Reference

`#include <fhe_stats.h>`

Public Member Functions

- fhe_stats_record (const char *_name)
- void update (double val)
- void save (double val)

Public Attributes

- const char * name
- long count
- double sum
- double max
- std::vector< double > saved_values

Static Public Attributes

- static std::vector< fhe_stats_record * > map

7.50.1 Constructor & Destructor Documentation

7.50.1.1 fhe_stats_record()

```
helib::fhe_stats_record::fhe_stats_record (
             const char * _name )
```

7.50.2 Member Function Documentation

7.50.2.1 save()

```
void helib::fhe_stats_record::save (
             double val )
```

7.50.2.2 update()

```
void helib::fhe_stats_record::update (
             double val )
```

7.50.3 Member Data Documentation

7.50.3.1 count

```
long helib::fhe_stats_record::count
```

7.50.3.2 map

```
std::vector<fhe_stats_record*> helib::fhe_stats_record::map  [static]
```

7.50.3.3 max

```
double helib::fhe_stats_record::max
```

7.50.3.4 name

```
const char* helib::fhe_stats_record::name
```

7.50.3.5 saved_values

```
std::vector<double> helib::fhe_stats_record::saved_values
```

7.50.3.6 sum

```
double helib::fhe_stats_record::sum
```

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

- /HElib/include/helib/fhe_stats.h
- /HElib/src/fhe_stats.cpp

7.51 helib::FHEtimer Class Reference

A simple class to accumulate time.

```
#include <timing.h>
```

Public Member Functions

- FHEtimer (const char ∗_name, const char ∗_loc)
- void reset ()
- double getTime () const
- long getNumCalls () const

Public Attributes

- const char ∗ name
- const char ∗ loc
- HELIB_atomic_ulong counter
- HELIB_atomic_long numCalls

7.51.1 Detailed Description

A simple class to accumulate time.

7.51.2 Constructor & Destructor Documentation

7.51.2.1 FHEtimer()

```
helib::FHEtimer::FHEtimer (
            const char * _name,
            const char * _loc )  [inline]
```

7.51.3 Member Function Documentation

7.51.3.1 getNumCalls()

```
long helib::FHEtimer::getNumCalls ( ) const
```

7.51.3.2 getTime()

```
double helib::FHEtimer::getTime ( ) const
```

7.51.3.3 reset()

```
void helib::FHEtimer::reset ( )
```

7.51.4 Member Data Documentation

7.51.4.1 counter

```
HELIB_atomic_ulong helib::FHEtimer::counter
```

7.51.4.2 loc

```
const char* helib::FHEtimer::loc
```

7.51.4.3 name

```
const char* helib::FHEtimer::name
```

7.51.4.4 numCalls

```
HELIB_atomic_long helib::FHEtimer::numCalls
```

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

- /HElib/include/helib/timing.h
- /HElib/src/timing.cpp

7.52 helib::FlowEdge Class Reference

An edge in a flow graph.

```
#include <matching.h>
```

Public Member Functions

- FlowEdge (long c=0, long f=0)

Public Attributes

- long capacity
- long flow

7.52.1 Detailed Description

An edge in a flow graph.

7.52.2 Constructor & Destructor Documentation

7.52.2.1 FlowEdge()

```
helib::FlowEdge::FlowEdge (
            long c = 0,
            long f = 0 )  [inline], [explicit]
```

7.52.3 Member Data Documentation

7.52.3.1 capacity

```
long helib::FlowEdge::capacity
```

7.52.3.2 flow

```
long helib::FlowEdge::flow
```

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

- /HElib/include/helib/matching.h

7.53 helib::frobeniusAutomorph_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, long j)
- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, const NTL::Vec< long > &vec)

7.53.1 Member Function Documentation

7.53.1.1 apply() [1/2]

```
template<typename type >
static void helib::frobeniusAutomorph_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            const NTL::Vec< long > & vec )  [inline], [static]
```

7.53.1.2 apply() [2/2]

```
template<typename type >
static void helib::frobeniusAutomorph_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            long j ) [inline], [static]
```

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

- /HElib/src/EncryptedArray.cpp

7.54 helib::FullBinaryTree Class Reference

A simple implementation of full binary trees (each non-leaf has 2 children)

`#include <permutations.h>`

Public Member Functions

- FullBinaryTree (long _aux=0)
- FullBinaryTree (const T &d, long _aux=0)
- void putDataInRoot (const T &d)
- long size ()
- TreeNode< T > & operator[ ] (long i)
- const TreeNode< T > & operator[ ] (long i) const
- TreeNode< T > & at (long i)
- const TreeNode< T > & at (long i) const
- T & DataOfNode (long i)
- const T & DataOfNode (long i) const
- long getAuxKey () const
- void setAuxKey (long _aux)
- long getNleaves () const
- long firstLeaf () const
- long nextLeaf (long i) const
- long prevLeaf (long i) const
- long lastLeaf () const
- long rootIdx () const
- long parentIdx (long i) const
- long leftChildIdx (long i) const
- long rightChildIdx (long i) const
- void printout (std::ostream &s, long idx=0) const
- long addChildren (long prntIdx, const T &leftData, const T &rightData)
- void collapseToRoot ()

    Remove all nodes in the tree except for the root.

7.54.1 Detailed Description

A simple implementation of full binary trees (each non-leaf has 2 children)

7.54.2 Constructor & Destructor Documentation

7.54.2.1 FullBinaryTree() [1/2]

```
helib::FullBinaryTree::FullBinaryTree (
             long _aux = 0 )  [inline]
```

7.54.2.2 FullBinaryTree() [2/2]

```
helib::FullBinaryTree::FullBinaryTree (
             const T & d,
             long _aux = 0 )  [inline], [explicit]
```

7.54.3 Member Function Documentation

7.54.3.1 addChildren()

```
long helib::FullBinaryTree::addChildren (
             long prntIdx,
             const T & leftData,
             const T & rightData )
```

If the parent is a leaf, add to it to children with the given data, else just update the data of the two children of this parent. Returns the index of the left child, the right-child index is one more than the left-child index.

7.54.3.2 at() [1/2]

```
TreeNode<T>& helib::FullBinaryTree::at (
             long i )  [inline]
```

7.54.3.3 at() [2/2]

```
const TreeNode<T>& helib::FullBinaryTree::at (
             long i ) const  [inline]
```

7.54.3.4 collapseToRoot()

```
void helib::FullBinaryTree::collapseToRoot ( )  [inline]
```

Remove all nodes in the tree except for the root.

7.54.3.5 DataOfNode() [1/2]

```
T& helib::FullBinaryTree::DataOfNode (
             long i )  [inline]
```

7.54.3.6 DataOfNode() [2/2]

```
const T& helib::FullBinaryTree::DataOfNode (
             long i ) const  [inline]
```

7.54.3.7 firstLeaf()

```
long helib::FullBinaryTree::firstLeaf ( ) const  [inline]
```

7.54.3.8 getAuxKey()

```
long helib::FullBinaryTree::getAuxKey ( ) const  [inline]
```

7.54.3.9 getNleaves()

```
long helib::FullBinaryTree::getNleaves ( ) const  [inline]
```

7.54.3.10 lastLeaf()

```
long helib::FullBinaryTree::lastLeaf ( ) const  [inline]
```

7.54.3.11 leftChildIdx()

```
long helib::FullBinaryTree::leftChildIdx (
            long i ) const  [inline]
```

7.54.3.12 nextLeaf()

```
long helib::FullBinaryTree::nextLeaf (
            long i ) const  [inline]
```

7.54.3.13 operator[]() [1/2]

```
TreeNode<T>& helib::FullBinaryTree::operator[] (
            long i )  [inline]
```

7.54.3.14 operator[]() [2/2]

```
const TreeNode<T>& helib::FullBinaryTree::operator[] (
            long i ) const  [inline]
```

7.54.3.15 parentIdx()

```
long helib::FullBinaryTree::parentIdx (
            long i ) const  [inline]
```

7.54.3.16 prevLeaf()

```
long helib::FullBinaryTree::prevLeaf (
            long i ) const  [inline]
```

7.54.3.17 printout()

```
void helib::FullBinaryTree::printout (
            std::ostream & s,
            long idx = 0 ) const  [inline]
```

7.54.3.18 putDataInRoot()

```
void helib::FullBinaryTree::putDataInRoot (
            const T & d )  [inline]
```

7.54.3.19 rightChildIdx()

```
long helib::FullBinaryTree::rightChildIdx (
            long i ) const  [inline]
```

7.54.3.20 rootIdx()

```
long helib::FullBinaryTree::rootIdx ( ) const  [inline]
```

7.54.3.21 setAuxKey()

```
void helib::FullBinaryTree::setAuxKey (
            long _aux )  [inline]
```

7.54.3.22 size()

```
long helib::FullBinaryTree::size ( )  [inline]
```

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

- /HElib/include/helib/permutations.h

7.55 helib::GenDescriptor Class Reference

A minimal description of a generator for the purpose of building tree.

```
#include <permutations.h>
```

Public Member Functions

- GenDescriptor (long _order, bool _good, long gen=0)
- GenDescriptor ()

Public Attributes

- long genIdx
- long order
- bool good

7.55.1 Detailed Description

A minimal description of a generator for the purpose of building tree.

7.55.2 Constructor & Destructor Documentation

7.55.2.1 GenDescriptor() [1/2]

```
helib::GenDescriptor::GenDescriptor (
            long _order,
            bool _good,
            long gen = 0 )  [inline]
```

7.55.2.2 GenDescriptor() [2/2]

```
helib::GenDescriptor::GenDescriptor ( )  [inline]
```

7.55.3 Member Data Documentation

7.55.3.1 genIdx

```
long helib::GenDescriptor::genIdx
```

7.55.3.2 good

```
bool helib::GenDescriptor::good
```

7.55.3.3 order

```
long helib::GenDescriptor::order
```

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

- /HElib/include/helib/permutations.h

7.56 helib::general_range< T > Class Template Reference

```
#include <range.h>
```

Classes

- class iterator

Public Member Functions

- iterator begin () const
- iterator end () const
- general_range (T begin, T end)

7.56.1 Constructor & Destructor Documentation

7.56.1.1 general_range()

```
template<typename T >
helib::general_range< T >::general_range (
            T begin,
            T end ) [inline]
```

7.56.2 Member Function Documentation

7.56.2.1 begin()

```
template<typename T >
iterator helib::general_range< T >::begin ( ) const [inline]
```

7.56.2.2 end()

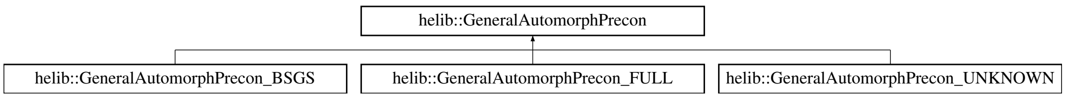
```
template<typename T >
iterator helib::general_range< T >::end ( ) const [inline]
```

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

- /HElib/include/helib/range.h

7.57 helib::GeneralAutomorphPrecon Class Reference

Inheritance diagram for helib::GeneralAutomorphPrecon:



Public Member Functions

- virtual ∼GeneralAutomorphPrecon ()
- virtual std::shared_ptr< Ctxt > automorph (long i) const =0

7.57.1 Constructor & Destructor Documentation

7.57.1.1 ∼GeneralAutomorphPrecon()

```
virtual helib::GeneralAutomorphPrecon::~GeneralAutomorphPrecon ( ) [inline], [virtual]
```

7.57.2 Member Function Documentation

7.57.2.1 automorph()

```
virtual std::shared_ptr<Ctxt> helib::GeneralAutomorphPrecon::automorph (
            long i ) const [pure virtual]
```

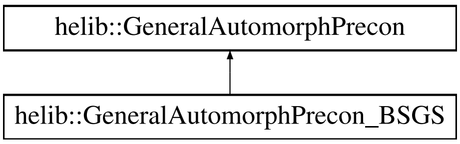
Implemented in helib::GeneralAutomorphPrecon_BSGS, helib::GeneralAutomorphPrecon_FULL, and helib::GeneralAutomorphPreco

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

- /HElib/src/matmul.cpp

7.58 helib::GeneralAutomorphPrecon_BSGS Class Reference

Inheritance diagram for helib::GeneralAutomorphPrecon_BSGS:



Public Member Functions

- GeneralAutomorphPrecon_BSGS (const Ctxt &_ctxt, long _dim, const EncryptedArray &ea)
- std::shared_ptr< Ctxt > automorph (long i) const override

7.58.1 Constructor & Destructor Documentation

7.58.1.1 GeneralAutomorphPrecon_BSGS()

```
helib::GeneralAutomorphPrecon_BSGS::GeneralAutomorphPrecon_BSGS (
            const Ctxt & _ctxt,
            long _dim,
            const EncryptedArray & ea ) [inline]
```

7.58.2 Member Function Documentation

7.58.2.1 automorph()

```
std::shared_ptr<Ctxt> helib::GeneralAutomorphPrecon_BSGS::automorph (
            long i ) const [inline], [override], [virtual]
```

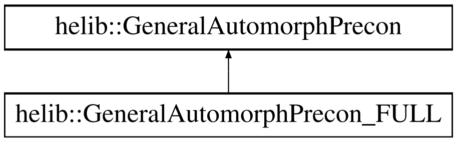
Implements helib::GeneralAutomorphPrecon.

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

- /HElib/src/matmul.cpp

7.59 helib::GeneralAutomorphPrecon_FULL Class Reference

Inheritance diagram for helib::GeneralAutomorphPrecon_FULL:



Public Member Functions

- GeneralAutomorphPrecon_FULL (const Ctxt &_ctxt, long _dim, const EncryptedArray &ea)
- std::shared_ptr< Ctxt > automorph (long i) const override

7.59.1 Constructor & Destructor Documentation

7.59.1.1 GeneralAutomorphPrecon_FULL()

```
helib::GeneralAutomorphPrecon_FULL::GeneralAutomorphPrecon_FULL (
            const Ctxt & _ctxt,
            long _dim,
            const EncryptedArray & ea )  [inline]
```

7.59.2 Member Function Documentation

7.59.2.1 automorph()

```
std::shared_ptr<Ctxt> helib::GeneralAutomorphPrecon_FULL::automorph (
            long i ) const  [inline], [override], [virtual]
```

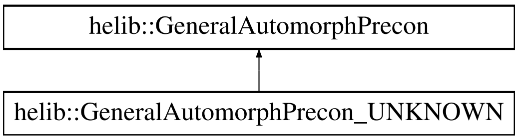
Implements helib::GeneralAutomorphPrecon.

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

- /HElib/src/matmul.cpp

7.60 helib::GeneralAutomorphPrecon_UNKNOWN Class Reference

Inheritance diagram for helib::GeneralAutomorphPrecon_UNKNOWN:



Public Member Functions

- GeneralAutomorphPrecon_UNKNOWN (const Ctxt &_ctxt, long _dim, const EncryptedArray &ea)
- std::shared_ptr< Ctxt > automorph (long i) const override

7.60.1 Constructor & Destructor Documentation

7.60.1.1 GeneralAutomorphPrecon_UNKNOWN()

```
helib::GeneralAutomorphPrecon_UNKNOWN::GeneralAutomorphPrecon_UNKNOWN (
            const Ctxt & _ctxt,
            long _dim,
            const EncryptedArray & ea )  [inline]
```

7.60.2 Member Function Documentation

7.60.2.1 automorph()

```
std::shared_ptr<Ctxt> helib::GeneralAutomorphPrecon_UNKNOWN::automorph (
            long i ) const  [inline], [override], [virtual]
```

Implements helib::GeneralAutomorphPrecon.

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

- /HElib/src/matmul.cpp

7.61 helib::GeneralBenesNetwork Class Reference

Implementation of generalized Benes Permutation Network.

```
#include <permutations.h>
```

Public Member Functions

- long getDepth () const
- long getSize () const
- long getNumLevels () const
- const NTL::Vec< short > & getLevel (long i) const
- long levelToDepthMap (long i) const
- long shamt (long i) const
- GeneralBenesNetwork (const Permut &perm)
- bool testNetwork (const Permut &perm) const

Static Public Member Functions

- static long depth (long n)
- static long levelToDepthMap (UNUSED long n, long k, long i)
- static long shamt (long n, long k, long i)

7.61.1 Detailed Description

Implementation of generalized Benes Permutation Network.

7.61.2 Constructor & Destructor Documentation

7.61.2.1 GeneralBenesNetwork()

```
helib::GeneralBenesNetwork::GeneralBenesNetwork (
            const Permut & perm )
```

7.61.3 Member Function Documentation

7.61.3.1 depth()

```
static long helib::GeneralBenesNetwork::depth (
            long n ) [inline], [static]
```

computes recursion depth k for generalized Benes network of size n. the actual number of levels in the network is 2∗k-1

7.61.3.2 getDepth()

```
long helib::GeneralBenesNetwork::getDepth ( ) const [inline]
```

7.61.3.3 getLevel()

```
const NTL::Vec<short>& helib::GeneralBenesNetwork::getLevel (
            long i ) const  [inline]
```

7.61.3.4 getNumLevels()

```
long helib::GeneralBenesNetwork::getNumLevels ( ) const  [inline]
```

7.61.3.5 getSize()

```
long helib::GeneralBenesNetwork::getSize ( ) const  [inline]
```

7.61.3.6 levelToDepthMap() [1/2]

```
long helib::GeneralBenesNetwork::levelToDepthMap (
            long i ) const  [inline]
```

7.61.3.7 levelToDepthMap() [2/2]

```
static long helib::GeneralBenesNetwork::levelToDepthMap (
            UNUSED long n,
            long k,
            long i )  [inline], [static]
```

maps a level number i = 0..2∗k-2 to a recursion depth d = 0..k-1 using the formula d = (k-1)-|(k-1)-i|

7.61.3.8 shamt() [1/2]

```
long helib::GeneralBenesNetwork::shamt (
            long i ) const  [inline]
```

7.61.3.9 shamt() [2/2]

```
static long helib::GeneralBenesNetwork::shamt (
            long n,
            long k,
            long i )  [inline], [static]
```

shift amount for level number i=0..2∗k-2 using the formula ceil(floor(n/2^d) / 2), where d = levelToDepthMap(i)

7.61.3.10 testNetwork()

```
bool helib::GeneralBenesNetwork::testNetwork (
            const Permut & perm ) const
```

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

- /HElib/include/helib/permutations.h
- /HElib/src/BenesNetwork.cpp

7.62 helib::GeneratorTrees Class Reference

A std::vector of generator trees, one per generator in Zm∗/(p)

```
#include <permutations.h>
```

Public Member Functions

- GeneratorTrees ()
- long numLayers () const
- long numTrees () const
- long getSize () const
- OneGeneratorTree & operator[ ] (long i)
- const OneGeneratorTree & operator[ ] (long i) const
- OneGeneratorTree & at (long i)
- const OneGeneratorTree & at (long i) const
- OneGeneratorTree & getGenTree (long i)
- const OneGeneratorTree & getGenTree (long i) const
- const Permut & mapToCube () const
- const Permut & mapToArray () const
- Permut & mapToCube ()
- Permut & mapToArray ()
- long mapToCube (long i) const
- long mapToArray (long i) const
- void getCubeDims (NTL::Vec< long > &dims) const
- void getCubeSubDims (NTL::Vec< long > &dims) const
- long buildOptimalTrees (const NTL::Vec< GenDescriptor > &vec, long depthBound)
- void ComputeCubeMapping ()

  Computes permutations mapping between linear array and the cube.

Friends

- std::ostream & operator<< (std::ostream &s, const GeneratorTrees &t)

7.62.1 Detailed Description

A std::vector of generator trees, one per generator in Zm∗/(p)

7.62.2 Constructor & Destructor Documentation

7.62.2.1 GeneratorTrees()

```
helib::GeneratorTrees::GeneratorTrees ( )  [inline]
```

7.62.3 Member Function Documentation

7.62.3.1 at() [1/2]

```
OneGeneratorTree& helib::GeneratorTrees::at (
            long i )  [inline]
```

7.62.3.2 at() [2/2]

```
const OneGeneratorTree& helib::GeneratorTrees::at (
            long i ) const  [inline]
```

7.62.3.3 buildOptimalTrees()

```
long helib::GeneratorTrees::buildOptimalTrees (
            const NTL::Vec< GenDescriptor > & vec,
            long depthBound )
```

Compute the trees corresponding to the "optimal" way of breaking a permutation into dimensions, subject to some constraints. Returns the cost (# of 1D shifts) of this solution. Returns NTL_MAX_LONG if no solution

7.62.3.4 ComputeCubeMapping()

```
void helib::GeneratorTrees::ComputeCubeMapping ( )
```

Computes permutations mapping between linear array and the cube.

If the cube dimensions (i.e., leaves of tree) are n1,n2,...,nt and N=\prod_j n_j is the size of the cube, then an integer i can be represented in either the mixed base of the n_j's or in "CRT basis" relative to the leaves: Namely either i = \sum_{j<=t} i_j * \prod_{k>j} n_k, or i = \sum_leaf i'_leaf * leaf.e mod N.

The breakPermByDim procedure expects its input in the mixed-base representation, and the maps are used to convert back and forth. Specifically, let (i'_1,...,i'_t) be the CRT representation of i in this cube, and j = \sum_{j=1}^t i'_j * \prod_{k>j} n_k, then we have map2cube[i]=j and map2array[j]=i.

7.62.3.5 getCubeDims()

```
void helib::GeneratorTrees::getCubeDims (
            NTL::Vec< long > & dims ) const
```

Get the "crude" cube dimensions corresponding to the vector of trees, the ordered vector with one dimension per tree

7.62.3.6 getCubeSubDims()

```
void helib::GeneratorTrees::getCubeSubDims (
            NTL::Vec< long > & dims ) const
```

Get the "fine" cube dimensions corresponding to the vector of trees, the ordered vector with one dimension per leaf in all the trees.

7.62.3.7 getGenTree() [1/2]

```
OneGeneratorTree& helib::GeneratorTrees::getGenTree (
            long i )  [inline]
```

7.62.3.8 getGenTree() [2/2]

```
const OneGeneratorTree& helib::GeneratorTrees::getGenTree (
            long i ) const  [inline]
```

7.62.3.9 getSize()

```
long helib::GeneratorTrees::getSize ( ) const  [inline]
```

7.62.3.10 mapToArray() [1/3]

```
Permut& helib::GeneratorTrees::mapToArray ( )  [inline]
```

7.62.3.11 mapToArray() [2/3]

```
const Permut& helib::GeneratorTrees::mapToArray ( ) const  [inline]
```

7.62.3.12 mapToArray() [3/3]

```
long helib::GeneratorTrees::mapToArray (
            long i ) const  [inline]
```

7.62.3.13 mapToCube() [1/3]

```
Permut& helib::GeneratorTrees::mapToCube ( )  [inline]
```

7.62.3.14 mapToCube() [2/3]

```
const Permut& helib::GeneratorTrees::mapToCube ( ) const  [inline]
```

7.62.3.15 mapToCube() [3/3]

```
long helib::GeneratorTrees::mapToCube (
            long i ) const  [inline]
```

7.62.3.16 numLayers()

```
long helib::GeneratorTrees::numLayers ( ) const  [inline]
```

7.62.3.17 numTrees()

```
long helib::GeneratorTrees::numTrees ( ) const  [inline]
```

7.62.3.18 operator[]() [1/2]

```
OneGeneratorTree& helib::GeneratorTrees::operator[] (
            long i )  [inline]
```

7.62.3.19 operator[]() [2/2]

```
const OneGeneratorTree& helib::GeneratorTrees::operator[] (
            long i ) const  [inline]
```

7.62.4 Friends And Related Function Documentation

7.62.4.1 operator<<

```
std::ostream& operator<< (
            std::ostream & s,
            const GeneratorTrees & t )  [friend]
```

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

- /HElib/include/helib/permutations.h
- /HElib/src/OptimizePermutations.cpp
- /HElib/src/permutations.cpp

7.63 helib::half_FFT Struct Reference

```
#include <PAlgebra.h>
```

Public Member Functions

- half_FFT (long m)

Public Attributes

- PGFFT fft
- std::vector< std::complex< double > > pow

7.63.1 Constructor & Destructor Documentation

7.63.1.1 half_FFT()

```
helib::half_FFT::half_FFT (
            long m )
```

7.63.2 Member Data Documentation

7.63.2.1 fft

```
PGFFT helib::half_FFT::fft
```

7.63.2.2 pow

```
std::vector<std::complex<double> > helib::half_FFT::pow
```

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

- /HElib/include/helib/PAlgebra.h
- /HElib/src/PAlgebra.cpp

7.64 HighLvlTimingData Class Reference

Public Member Functions

- HighLvlTimingData (long _lvl=-1)

Public Attributes

- long lvl
- double rotate
- double shift
- double permute
- double matmul
- double replicate
- double replAll

7.64.1 Constructor & Destructor Documentation

7.64.1.1 HighLvlTimingData()

```
HighLvlTimingData::HighLvlTimingData (
            long _lvl = -1 )  [inline], [explicit]
```

7.64.2 Member Data Documentation

7.64.2.1 lvl

```
long HighLvlTimingData::lvl
```

7.64.2.2 matmul

```
double HighLvlTimingData::matmul
```

7.64.2.3 permute

```
double HighLvlTimingData::permute
```

7.64.2.4 replAll

```
double HighLvlTimingData::replAll
```

7.64.2.5 replicate

```
double HighLvlTimingData::replicate
```

7.64.2.6 rotate

```
double HighLvlTimingData::rotate
```

7.64.2.7 shift

```
double HighLvlTimingData::shift
```

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

- /HElib/src/Test_Timing.cpp

7.65 helib::HyperCube< T > Class Template Reference

A multi-dimensional cube.

`#include <hypercube.h>`

Public Member Functions

- HyperCube (const HyperCube &other)=default
- HyperCube (const CubeSignature &_sig)

    initialize a HyperCube with a CubeSignature
- HyperCube & operator= (const HyperCube< T > &other)

    assignment: signatures must be the same
- bool operator== (const HyperCube< T > &other) const

    equality testing: signatures must be the same
- bool operator!= (const HyperCube< T > &other) const
- const CubeSignature & getSig () const

    const ref to signature
- NTL::Vec< T > & getData ()
- const NTL::Vec< T > & getData () const

    read-only ref to data vector
- long getSize () const

    total size of cube
- long getNumDims () const

    number of dimensions
- long getDim (long d) const

    size of dimension d
- long getProd (long d) const

    product of sizes of dimensions d, d+1, ...
- long getProd (long from, long to) const

    product of sizes of dimensions from, from+1, ..., to-1
- long getCoord (long i, long d) const

    get coordinate in dimension d of index i
- long addCoord (long i, long d, long offset) const

    add offset to coordinate in dimension d of index i
- long numSlices (long d=1) const

    number of slices
- long sliceSize (long d=1) const

    size of one slice
- long numCols () const

    number of columns
- T & at (long i)

    reference to element at position i, with bounds check
- T & operator[ ] (long i)

    reference to element at position i, without bounds check
- const T & at (long i) const

    read-only reference to element at position i, with bounds check
- const T & operator[ ] (long i) const

    read-only reference to element at position i, without bounds check
- void rotate1D (long i, long k)

    rotate k positions along the i'th dimension
- void shift1D (long i, long k)

    Shift k positions along the i'th dimension with zero fill.

7.65.1 Detailed Description

template<typename T>
class helib::HyperCube< T >

A multi-dimensional cube.

Such an object is initialized with a CubeSignature: a reference to the signature is stored with the cube, and so the signature must remain alive during the lifetime of the cube, to prevent dangling pointers.

7.65.2 Constructor & Destructor Documentation

7.65.2.1 HyperCube() [1/2]

```
template<typename T >
helib::HyperCube< T >::HyperCube (
            const HyperCube< T > & other )  [default]
```

7.65.2.2 HyperCube() [2/2]

```
template<typename T >
helib::HyperCube< T >::HyperCube (
            const CubeSignature & _sig )  [inline]
```

initialize a HyperCube with a CubeSignature

7.65.3 Member Function Documentation

7.65.3.1 addCoord()

```
template<typename T >
long helib::HyperCube< T >::addCoord (
            long i,
            long d,
            long offset ) const  [inline]
```

add offset to coordinate in dimension d of index i

7.65.3.2 at() [1/2]

```
template<typename T >
T& helib::HyperCube< T >::at (
            long i ) [inline]
```

reference to element at position i, with bounds check

7.65.3.3 at() [2/2]

```
template<typename T >
const T& helib::HyperCube< T >::at (
            long i ) const [inline]
```

read-only reference to element at position i, with bounds check

7.65.3.4 getCoord()

```
template<typename T >
long helib::HyperCube< T >::getCoord (
            long i,
            long d ) const [inline]
```

get coordinate in dimension d of index i

7.65.3.5 getData() [1/2]

```
template<typename T >
NTL::Vec<T>& helib::HyperCube< T >::getData ( ) [inline]
```

read/write ref to the data vector. Note that the length of data is fixed upon construction, so it cannot be changed through this ref.

7.65.3.6 getData() [2/2]

```
template<typename T >
const NTL::Vec<T>& helib::HyperCube< T >::getData ( ) const [inline]
```

read-only ref to data vector

7.65.3.7 getDim()

```
template<typename T >
long helib::HyperCube< T >::getDim (
            long d ) const  [inline]
```

size of dimension d

7.65.3.8 getNumDims()

```
template<typename T >
long helib::HyperCube< T >::getNumDims ( ) const  [inline]
```

number of dimensions

7.65.3.9 getProd() [1/2]

```
template<typename T >
long helib::HyperCube< T >::getProd (
            long d ) const  [inline]
```

product of sizes of dimensions d, d+1, ...

7.65.3.10 getProd() [2/2]

```
template<typename T >
long helib::HyperCube< T >::getProd (
            long from,
            long to ) const  [inline]
```

product of sizes of dimensions from, from+1, ..., to-1

7.65.3.11 getSig()

```
template<typename T >
const CubeSignature& helib::HyperCube< T >::getSig ( ) const  [inline]
```

const ref to signature

7.65.3.12 getSize()

```
template<typename T >
long helib::HyperCube< T >::getSize ( ) const  [inline]
```

total size of cube

7.65.3.13 numCols()

```
template<typename T >
long helib::HyperCube< T >::numCols ( ) const  [inline]
```

number of columns

7.65.3.14 numSlices()

```
template<typename T >
long helib::HyperCube< T >::numSlices (
            long d = 1 ) const  [inline]
```

number of slices

7.65.3.15 operator"!=()

```
template<typename T >
bool helib::HyperCube< T >::operator!= (
            const HyperCube< T > & other ) const  [inline]
```

7.65.3.16 operator=()

```
template<typename T >
HyperCube& helib::HyperCube< T >::operator= (
            const HyperCube< T > & other )  [inline]
```

assignment: signatures must be the same

7.65.3.17 operator==()

```
template<typename T >
bool helib::HyperCube< T >::operator== (
            const HyperCube< T > & other ) const  [inline]
```

equality testing: signatures must be the same

7.65.3.18 operator[]() [1/2]

```
template<typename T >
T& helib::HyperCube< T >::operator[] (
            long i )  [inline]
```

reference to element at position i, without bounds check

7.65.3.19 operator[]() [2/2]

```
template<typename T >
const T& helib::HyperCube< T >::operator[] (
            long i ) const  [inline]
```

read-only reference to element at position i, without bounds check

7.65.3.20 rotate1D()

```
template<typename T >
void helib::HyperCube< T >::rotate1D (
            long i,
            long k )
```

rotate k positions along the i'th dimension

7.65.3.21 shift1D()

```
template<typename T >
void helib::HyperCube< T >::shift1D (
            long i,
            long k )
```

Shift k positions along the i'th dimension with zero fill.

7.65.3.22 sliceSize()

```
template<typename T >
long helib::HyperCube< T >::sliceSize (
            long d = 1 ) const  [inline]
```

size of one slice

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

- /HElib/include/helib/hypercube.h
- /HElib/src/hypercube.cpp

7.66 helib::IndexMap< T > Class Template Reference

IndexMap<T> implements a generic map indexed by a dynamic index set.

```
#include <IndexMap.h>
```

Public Member Functions

- IndexMap ()

    The empty map.
- IndexMap (IndexMapInit< T > *_init)

    A map with an initialization object. This associates a method for initializing new elements in the map. When a new index j is added to the index set, an object t of type T is created using the default constructor for T, after which the function _init->init(t) is called (t is passed by reference). To use this feature, you need to derive a subclass of IndexMapInit<T> that defines the init function. This "helper object" should be created using operator new, and the pointer is "exclusively owned" by the map object.
- const IndexSet & getIndexSet () const

    Get the underlying index set.
- T & operator[ ] (long j)

    Access functions: will raise an error if j does not belong to the current index set.
- const T & operator[ ] (long j) const
- void insert (long j)

    Insert indexes to the IndexSet. Insertion will cause new T objects to be created, using the default constructor, and possibly initialized via the IndexMapInit<T> pointer.
- void insert (const IndexSet &s)
- void remove (long j)

    Delete indexes from IndexSet, may cause objects to be destroyed.
- void remove (const IndexSet &s)
- void clear ()

7.66.1 Detailed Description

template<typename T>
class helib::IndexMap< T >

IndexMap<T> implements a generic map indexed by a dynamic index set.

Additionally, it allows new elements of the map to be initialized in a flexible manner.

7.66.2 Constructor & Destructor Documentation

7.66.2.1 IndexMap() [1/2]

```
template<typename T >
helib::IndexMap< T >::IndexMap ( )
```

The empty map.

7.66.2.2 IndexMap() [2/2]

```
template<typename T >
helib::IndexMap< T >::IndexMap (
            IndexMapInit< T > * _init )  [inline], [explicit]
```

A map with an initialization object. This associates a method for initializing new elements in the map. When a new index j is added to the index set, an object t of type T is created using the default constructor for T, after which the function _init->init(t) is called (t is passed by reference). To use this feature, you need to derive a subclass of IndexMapInit<T> that defines the init function. This "helper object" should be created using operator new, and the pointer is "exclusively owned" by the map object.

7.66.3 Member Function Documentation

7.66.3.1 clear()

```
template<typename T >
void helib::IndexMap< T >::clear ( )  [inline]
```

7.66.3.2 getIndexSet()

```
template<typename T >
const IndexSet& helib::IndexMap< T >::getIndexSet ( ) const  [inline]
```

Get the underlying index set.

7.66.3.3 insert() [1/2]

```
template<typename T >
void helib::IndexMap< T >::insert (
            const IndexSet & s ) [inline]
```

7.66.3.4 insert() [2/2]

```
template<typename T >
void helib::IndexMap< T >::insert (
            long j ) [inline]
```

Insert indexes to the IndexSet. Insertion will cause new T objects to be created, using the default constructor, and possibly initialized via the IndexMapInit<T> pointer.

7.66.3.5 operator[]() [1/2]

```
template<typename T >
T& helib::IndexMap< T >::operator[] (
            long j ) [inline]
```

Access functions: will raise an error if j does not belong to the current index set.

7.66.3.6 operator[]() [2/2]

```
template<typename T >
const T& helib::IndexMap< T >::operator[] (
            long j ) const [inline]
```

7.66.3.7 remove() [1/2]

```
template<typename T >
void helib::IndexMap< T >::remove (
            const IndexSet & s ) [inline]
```

7.66.3.8 remove() [2/2]

```
template<typename T >
void helib::IndexMap< T >::remove (
            long j )  [inline]
```

Delete indexes from IndexSet, may cause objects to be destroyed.

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

- /HElib/include/helib/IndexMap.h

7.67 helib::IndexMapInit< T > Class Template Reference

Initializing elements in an IndexMap.

```
#include <IndexMap.h>
```

Public Member Functions

- virtual void init (T &)=0

    Initialization function, override with initialization code.
- virtual IndexMapInit< T > * clone () const =0

    Cloning a pointer, override with code to create a fresh copy.
- virtual ∼IndexMapInit ()

7.67.1 Detailed Description

template<typename T>
class helib::IndexMapInit< T >

Initializing elements in an IndexMap.

7.67.2 Constructor & Destructor Documentation

7.67.2.1 ∼IndexMapInit()

```
template<typename T >
virtual helib::IndexMapInit< T >::∼IndexMapInit ( )  [inline], [virtual]
```

7.67.3 Member Function Documentation

7.67.3.1 clone()

```
template<typename T >
virtual IndexMapInit<T>* helib::IndexMapInit< T >::clone ( ) const [pure virtual]
```

Cloning a pointer, override with code to create a fresh copy.

7.67.3.2 init()

```
template<typename T >
virtual void helib::IndexMapInit< T >::init (
            T & ) [pure virtual]
```

Initialization function, override with initialization code.

Implemented in helib::DoubleCRTHelper.

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

- /HElib/include/helib/IndexMap.h

7.68 helib::IndexSet Class Reference

A dynamic set of non-negative integers.

```
#include <IndexSet.h>
```

Classes

- class iterator

Public Member Functions

- IndexSet ()
- IndexSet (long low, long high)
- IndexSet (long j)
- long first () const

  Returns the first element, 0 if the set is empty.
- long last () const

  Returns the last element, -1 if the set is empty.
- long next (long j) const

  Returns the next element after j, if any; otherwise j+1.
- long prev (long j) const
- long card () const

  The cardinality of the set.
- bool contains (long j) const

  Returns true iff the set contains j.

- bool contains (const IndexSet &s) const

    Returns true iff the set contains s.
- bool disjointFrom (const IndexSet &s) const

    Returns true iff the set is disjoint from s.
- bool operator== (const IndexSet &s) const
- bool operator!= (const IndexSet &s) const
- void clear ()

    Set to the empty set.
- void insert (long j)

    Add j to the set.
- void remove (long j)

    Remove j from the set.
- void insert (const IndexSet &s)

    Add s to the set (union)
- void remove (const IndexSet &s)

    Remove s from the set (set minus)
- void retain (const IndexSet &s)

    Retains only those elements that are also in s (intersection)
- bool isInterval () const

    Is this set a contiguous interval?
- void read (std::istream &str)
- void write (std::ostream &str) const
- iterator begin () const
- iterator end () const

Static Public Member Functions

- static const IndexSet & emptySet ()

    Read-only access to an empty set.

7.68.1 Detailed Description

A dynamic set of non-negative integers.

You can iterate through a set as follows:

```
for (long i = s.first(); i <= s.last(); i = s.next(i)) ...
for (long i = s.last(); i >= s.first(); i = s.prev(i)) ...
```

7.68.2 Constructor & Destructor Documentation

7.68.2.1 IndexSet() [1/3]

```
helib::IndexSet::IndexSet ( )  [inline]
```

7.68.2.2 IndexSet() [2/3]

```
helib::IndexSet::IndexSet (
            long low,
            long high )  [inline]
```

7.68.2.3 IndexSet() [3/3]

```
helib::IndexSet::IndexSet (
            long j )  [inline], [explicit]
```

7.68.3 Member Function Documentation

7.68.3.1 begin()

```
iterator helib::IndexSet::begin ( ) const  [inline]
```

7.68.3.2 card()

```
long helib::IndexSet::card ( ) const  [inline]
```

The cardinality of the set.

7.68.3.3 clear()

```
void helib::IndexSet::clear ( )
```

Set to the empty set.

7.68.3.4 contains() [1/2]

```
bool helib::IndexSet::contains (
            const IndexSet & s ) const
```

Returns true iff the set contains s.

7.68.3.5 contains() [2/2]

```
bool helib::IndexSet::contains (
             long j ) const
```

Returns true iff the set contains j.

7.68.3.6 disjointFrom()

```
bool helib::IndexSet::disjointFrom (
             const IndexSet & s ) const
```

Returns true iff the set is disjoint from s.

7.68.3.7 emptySet()

```
const IndexSet & helib::IndexSet::emptySet ( )  [static]
```

Read-only access to an empty set.

7.68.3.8 end()

```
iterator helib::IndexSet::end ( ) const  [inline]
```

7.68.3.9 first()

```
long helib::IndexSet::first ( ) const  [inline]
```

Returns the first element, 0 if the set is empty.

7.68.3.10 insert() [1/2]

```
void helib::IndexSet::insert (
             const IndexSet & s )
```

Add s to the set (union)

7.68.3.11 insert() [2/2]

```
void helib::IndexSet::insert (
            long j )
```

Add j to the set.

7.68.3.12 isInterval()

```
bool helib::IndexSet::isInterval ( ) const  [inline]
```

Is this set a contiguous interval?

7.68.3.13 last()

```
long helib::IndexSet::last ( ) const  [inline]
```

Returns the last element, -1 if the set is empty.

7.68.3.14 next()

```
long helib::IndexSet::next (
            long j ) const
```

Returns the next element after j, if any; otherwise j+1.

7.68.3.15 operator"!=()

```
bool helib::IndexSet::operator!= (
            const IndexSet & s ) const  [inline]
```

7.68.3.16 operator==()

```
bool helib::IndexSet::operator== (
            const IndexSet & s ) const
```

7.68.3.17 prev()

```
long helib::IndexSet::prev (
            long j ) const
```

7.68.3.18 read()

```
void helib::IndexSet::read (
            std::istream & str )
```

7.68.3.19 remove() [1/2]

```
void helib::IndexSet::remove (
            const IndexSet & s )
```

Remove s from the set (set minus)

7.68.3.20 remove() [2/2]

```
void helib::IndexSet::remove (
            long j )
```

Remove j from the set.

7.68.3.21 retain()

```
void helib::IndexSet::retain (
            const IndexSet & s )
```

Retains only those elements that are also in s (intersection)

7.68.3.22 write()

```
void helib::IndexSet::write (
            std::ostream & str ) const
```

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

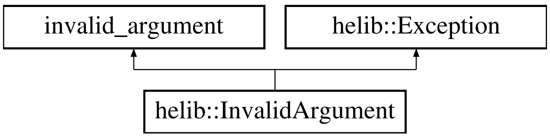
- /HElib/include/helib/IndexSet.h
- /HElib/src/IndexSet.cpp

7.69 helib::InvalidArgument Class Reference

Inherits from Exception and std::invalid_argument.

```
#include <exceptions.h>
```

Inheritance diagram for helib::InvalidArgument:



Public Member Functions

- InvalidArgument (const std::string &what_arg)
- InvalidArgument (const char ∗what_arg)
- virtual ∼InvalidArgument ()
- virtual const char ∗ what () const noexcept override

Additional Inherited Members

7.69.1 Detailed Description

Inherits from Exception and std::invalid_argument.

7.69.2 Constructor & Destructor Documentation

7.69.2.1 InvalidArgument() [1/2]

```
helib::InvalidArgument::InvalidArgument (
            const std::string & what_arg )  [inline], [explicit]
```

7.69.2.2 InvalidArgument() [2/2]

```
helib::InvalidArgument::InvalidArgument (
            const char * what_arg )  [inline], [explicit]
```

7.69.2.3 ∼InvalidArgument()

```
virtual helib::InvalidArgument::~InvalidArgument ( ) [inline], [virtual]
```

7.69.3 Member Function Documentation

7.69.3.1 what()

```
virtual const char* helib::InvalidArgument::what ( ) const [inline], [override], [virtual],
[noexcept]
```

Implements helib::Exception.

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

- /HElib/include/helib/exceptions.h

7.70 helib::IndexSet::iterator Class Reference

```
#include <IndexSet.h>
```

Public Member Functions

- long operator∗ () const
- iterator & operator++ ()
- bool operator== (const iterator &other) const
- bool operator!= (const iterator &other) const

Protected Member Functions

- iterator (const IndexSet &s, long i)

Friends

- class IndexSet

7.70.1 Constructor & Destructor Documentation

7.70.1.1 iterator()

```
helib::IndexSet::iterator::iterator (
            const IndexSet & s,
            long i )  [inline], [protected]
```

7.70.2 Member Function Documentation

7.70.2.1 operator"!=()

```
bool helib::IndexSet::iterator::operator!= (
            const iterator & other ) const  [inline]
```

7.70.2.2 operator∗()

```
long helib::IndexSet::iterator::operator* ( ) const  [inline]
```

7.70.2.3 operator++()

```
iterator& helib::IndexSet::iterator::operator++ ( )  [inline]
```

7.70.2.4 operator==()

```
bool helib::IndexSet::iterator::operator== (
            const iterator & other ) const  [inline]
```

7.70.3 Friends And Related Function Documentation

7.70.3.1 IndexSet

```
friend class IndexSet  [friend]
```

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

- /HElib/include/helib/IndexSet.h

7.71 helib::general_range< T >::iterator Class Reference

```
#include <range.h>
```

Public Member Functions

- T operator* () const
- iterator & operator++ ()
- bool operator== (const iterator &other) const
- bool operator!= (const iterator &other) const

Protected Member Functions

- iterator (T start)

Friends

- class general_range

7.71.1 Constructor & Destructor Documentation

7.71.1.1 iterator()

```
template<typename T >
helib::general_range< T >::iterator::iterator (
            T start ) [inline], [protected]
```

7.71.2 Member Function Documentation

7.71.2.1 operator"!=()

```
template<typename T >
bool helib::general_range< T >::iterator::operator!= (
            const iterator & other ) const [inline]
```

7.71.2.2 operator∗()

```
template<typename T >
T helib::general_range< T >::iterator::operator* ( ) const [inline]
```

7.71.2.3 operator++()

```
template<typename T >
iterator& helib::general_range< T >::iterator::operator++ ( ) [inline]
```

7.71.2.4 operator==()

```
template<typename T >
bool helib::general_range< T >::iterator::operator== (
            const iterator & other ) const [inline]
```

7.71.3 Friends And Related Function Documentation

7.71.3.1 general_range

```
template<typename T >
friend class general_range [friend]
```

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

- /HElib/include/helib/range.h

7.72 helib::KeySwitch Class Reference

Key-switching matrices.

```
#include <keySwitching.h>
```

Public Member Functions

- KeySwitch (long sPow=0, long xPow=0, long fromID=0, long toID=0, long p=0)
- KeySwitch (const SKHandle &_fromKey, long fromID=0, long toID=0, long p=0)
- bool operator== (const KeySwitch &other) const
- bool operator!= (const KeySwitch &other) const
- unsigned long NumCols () const
- bool isDummy () const
- void verify (SecKey &sk)

  A debugging method.
- void readMatrix (std::istream &str, const Context &context)

  Read a key-switching matrix from input.
- void read (std::istream &str, const Context &context)

  Raw IO.
- void write (std::ostream &str) const

Static Public Member Functions

- static const KeySwitch & dummy ()

  returns a dummy static matrix with toKeyId == -1

Public Attributes

- SKHandle fromKey
- long toKeyID
- long ptxtSpace
- std::vector< DoubleCRT > b
- NTL::ZZ prgSeed
- NTL::xdouble noiseBound

7.72.1 Detailed Description

Key-switching matrices.

There are basically two approaches for how to do key-switching: either decompose the mod-q ciphertext into bits (or digits) to make it low-norm, or perform the key-switching operation mod Q>>q. The tradeoff is that when decomposing the (coefficients of the) ciphertext into t digits, we need to increase the size of the key-switching matrix by a factor of t (and the running time similarly grows). On the other hand if we do not decompose at all then we need to work modulo Q>q^2, which means that the bitsize of our largest modulus q0 more than doubles (and hence also the parameter m more than doubles). In general if we decompose into digits of size B then we need to work with Q>q*B.)

The part of the spectrum where we expect to find the sweet spot is when we decompose the ciphertext into digits of size B=q0^{1/t} for some small constant t (maybe t=2,3 or so). This means that our largest modulus has to be Q>q0^{1+1/t}, which increases also the parameter m by a factor (1+1/t). It also means that for key-switching in the top levels we would break the ciphertext to t digits, hence the key-switching matrix will have t columns.

A key-switch matrix W[s'->s] converts a ciphertext-part with respect to secret-key polynomial s' into a canonical ciphertext (i.e. a two-part ciphertext with respect to (1,s)). The matrix W is a 2-by-t matrix of DoubleCRT objects. The bottom row are just (pseudo)random elements. Then for column j, if the bottom element is aj then the top element is set as bj = P*Bj*s' + p*ej - s * aj mod P*q0, where p is the plaintext space (i.e. 2 or 2^r, or 1 for CKKS) and Bj is the product of the digits-sizes corresponding to columns 0...i-1. (For example if we have digit sizes 3,5,7 then B0=1, B1=3, B2=15 and B3=105.) Also, q0 is the product of all the "ciphertext primes" and P is roughly the product of all the special primes. (Actually, for BGV, if Q is the product of all the special primes then P=Q*(Q^{-1} mod p).)

In this implementation we save some space, by keeping only a PRG seed for generating the pseudo-random elements, rather than the elements themselves.

To convert a ciphertext part R, we break R into digits R = sum_j Bj Rj, then set (q0,q1)^T = sum_j Rj * column-j. Note that we have <(1,s),(q0,q1)> = sum_j Rj*(s*aj - s*aj + p*ej +P*Bj*s') = P * sum_j Bj*Rj * s' + p sum_j Rj*ej = P * R * s' + p*a-small-element (mod P*q0) where the last element is small since the ej's are small and |Rj|<B. Note that if the ciphertext is encrypted relative to plaintext space p' and then key-switched with matrices W relative to plaintext space p, then we get a mew ciphertext with noise p'*small+p*small, so it is valid relative to plaintext space GCD(p',p).

The matrix W is defined modulo Q>t*B*sigma*q0 (with sigma a bound on the size of the ej's), and Q is the product of all the small primes in our moduli chain. However, if p is much smaller than B then is is enough to use W mod Qi with Qi a smaller modulus, Q>p*sigma*q0. Also note that if p<Br then we will be using only first r columns of the matrix W.

7.72.2 Constructor & Destructor Documentation

7.72.2.1 KeySwitch() [1/2]

```
helib::KeySwitch::KeySwitch (
            long sPow = 0,
            long xPow = 0,
            long fromID = 0,
            long toID = 0,
            long p = 0 )  [explicit]
```

7.72.2.2 KeySwitch() [2/2]

```
helib::KeySwitch::KeySwitch (
            const SKHandle & _fromKey,
            long fromID = 0,
            long toID = 0,
            long p = 0 )  [explicit]
```

7.72.3 Member Function Documentation

7.72.3.1 dummy()

```
const KeySwitch & helib::KeySwitch::dummy ( )  [static]
```

returns a dummy static matrix with toKeyId == -1

7.72.3.2 isDummy()

```
bool helib::KeySwitch::isDummy ( ) const
```

7.72.3.3 NumCols()

```
unsigned long helib::KeySwitch::NumCols ( ) const
```

7.72.3.4 operator"!=()

```
bool helib::KeySwitch::operator!= (
             const KeySwitch & other ) const
```

7.72.3.5 operator==()

```
bool helib::KeySwitch::operator== (
             const KeySwitch & other ) const
```

7.72.3.6 read()

```
void helib::KeySwitch::read (
             std::istream & str,
             const Context & context )
```

Raw IO.

7.72.3.7 readMatrix()

```
void helib::KeySwitch::readMatrix (
             std::istream & str,
             const Context & context )
```

Read a key-switching matrix from input.

7.72.3.8 verify()

```
void helib::KeySwitch::verify (
             SecKey & sk )
```

A debugging method.

7.72.3.9 write()

```
void helib::KeySwitch::write (
             std::ostream & str ) const
```

7.72.4 Member Data Documentation

7.72.4.1 b

```
std::vector<DoubleCRT> helib::KeySwitch::b
```

7.72.4.2 fromKey

```
SKHandle helib::KeySwitch::fromKey
```

7.72.4.3 noiseBound

```
NTL::xdouble helib::KeySwitch::noiseBound
```

7.72.4.4 prgSeed

```
NTL::ZZ helib::KeySwitch::prgSeed
```

7.72.4.5 ptxtSpace

```
long helib::KeySwitch::ptxtSpace
```

7.72.4.6 toKeyID

```
long helib::KeySwitch::toKeyID
```

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

- /HElib/include/helib/keySwitching.h
- /HElib/src/keySwitching.cpp

7.73 helib::LabeledEdge Class Reference

A generic directed edge in a graph with some labels.

```
#include <matching.h>
```

Public Member Functions

- LabeledEdge (long f, long t, long l=0, long c=0)

Public Attributes

- long from
- long to
- long label
- long color

7.73.1 Detailed Description

A generic directed edge in a graph with some labels.

7.73.2 Constructor & Destructor Documentation

7.73.2.1 LabeledEdge()

```
helib::LabeledEdge::LabeledEdge (
            long f,
            long t,
            long l = 0,
            long c = 0 )  [inline]
```

7.73.3 Member Data Documentation

7.73.3.1 color

```
long helib::LabeledEdge::color
```

7.73.3.2 from

```
long helib::LabeledEdge::from
```

7.73.3.3 label

```
long helib::LabeledEdge::label
```

7.73.3.4 to

```
long helib::LabeledEdge::to
```

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

- /HElib/include/helib/matching.h

7.74 helib::LabeledVertex Class Reference

A generic node in a graph with some labels.

```
#include <matching.h>
```

Public Member Functions

- LabeledVertex (long n, long l=0)
- void addEdge (long nn, long l=0, long c=0)
- void addNeighbor (long nn, long l=0, long c=0)

Public Attributes

- long name
- long label
- LNeighborList neighbors

7.74.1 Detailed Description

A generic node in a graph with some labels.

7.74.2 Constructor & Destructor Documentation

7.74.2.1 LabeledVertex()

```
helib::LabeledVertex::LabeledVertex (
            long n,
            long l = 0 )  [inline], [explicit]
```

7.74.3 Member Function Documentation

7.74.3.1 addEdge()

```
void helib::LabeledVertex::addEdge (
            long nn,
            long l = 0,
            long c = 0 )  [inline]
```

7.74.3.2 addNeighbor()

```
void helib::LabeledVertex::addNeighbor (
            long nn,
            long l = 0,
            long c = 0 )  [inline]
```

7.74.4 Member Data Documentation

7.74.4.1 label

```
long helib::LabeledVertex::label
```

7.74.4.2 name

```
long helib::LabeledVertex::name
```

7.74.4.3 neighbors

```
LNeighborList helib::LabeledVertex::neighbors
```

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

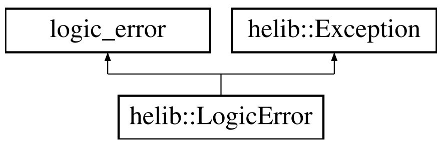
- /HElib/include/helib/matching.h

7.75 helib::LogicError Class Reference

Inherits from Exception and std::logic_error.

```
#include <exceptions.h>
```

Inheritance diagram for helib::LogicError:



Public Member Functions

- LogicError (const std::string &what_arg)
- LogicError (const char ∗what_arg)
- virtual ∼LogicError ()
- virtual const char ∗ what () const noexcept override

Additional Inherited Members

7.75.1 Detailed Description

Inherits from Exception and std::logic_error.

7.75.2 Constructor & Destructor Documentation

7.75.2.1 LogicError() [1/2]

```
helib::LogicError::LogicError (
            const std::string & what_arg )  [inline], [explicit]
```

7.75.2.2 LogicError() [2/2]

```
helib::LogicError::LogicError (
            const char * what_arg )  [inline], [explicit]
```

7.75.2.3 ∼LogicError()

```
virtual helib::LogicError::~LogicError ( )  [inline], [virtual]
```

7.75.3 Member Function Documentation

7.75.3.1 what()

```
virtual const char* helib::LogicError::what ( ) const  [inline], [override], [virtual], [noexcept]
```

Implements helib::Exception.

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

- /HElib/include/helib/exceptions.h

7.76 LowLvlTimingData Class Reference

Public Member Functions

- LowLvlTimingData (long _lvl=-1)

Public Attributes

- long lvl
- double addConst
- double add
- double multConst
- double mult
- double multBy2
- double autoNative
- double autoTypical
- double innerProd

7.76.1 Constructor & Destructor Documentation

7.76.1.1 LowLvlTimingData()

```
LowLvlTimingData::LowLvlTimingData (
             long _lvl = -1 )  [inline], [explicit]
```

7.76.2 Member Data Documentation

7.76.2.1 add

```
double LowLvlTimingData::add
```

7.76.2.2 addConst

```
double LowLvlTimingData::addConst
```

7.76.2.3 autoNative

```
double LowLvlTimingData::autoNative
```

7.76.2.4 autoTypical

```
double LowLvlTimingData::autoTypical
```

7.76.2.5 innerProd

```
double LowLvlTimingData::innerProd
```

7.76.2.6 lvl

```
long LowLvlTimingData::lvl
```

7.76.2.7 mult

```
double LowLvlTimingData::mult
```

7.76.2.8 multBy2

```
double LowLvlTimingData::multBy2
```

7.76.2.9 multConst

```
double LowLvlTimingData::multConst
```

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

- /HElib/src/Test_Timing.cpp

7.77 helib::MappingData< type > Class Template Reference

Auxiliary structure to support encoding/decoding slots.

```
#include <PAlgebra.h>
```

Public Member Functions

- const RX & getG () const
- long getDegG () const
- void restoreContextForG () const

Friends

- class PAlgebraModDerived< type >

7.77.1 Detailed Description

template<typename type>
class helib::MappingData< type >

Auxiliary structure to support encoding/decoding slots.

7.77.2 Member Function Documentation

7.77.2.1 getDegG()

```
template<typename type >
long helib::MappingData< type >::getDegG ( ) const [inline]
```

7.77.2.2 getG()

```
template<typename type >
const RX& helib::MappingData< type >::getG ( ) const [inline]
```

7.77.2.3 restoreContextForG()

```
template<typename type >
void helib::MappingData< type >::restoreContextForG ( ) const [inline]
```

7.77.3 Friends And Related Function Documentation

7.77.3.1 PAlgebraModDerived< type >

```
template<typename type >
friend class PAlgebraModDerived< type > [friend]
```

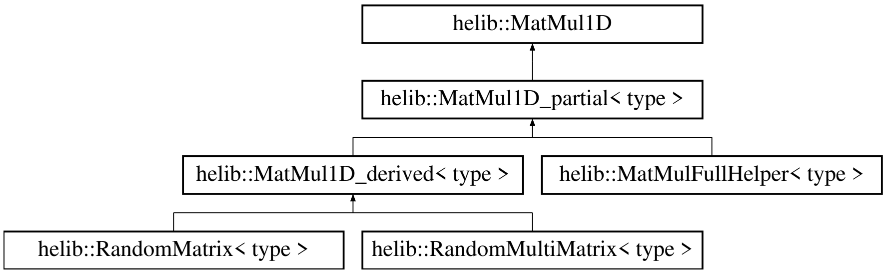
The documentation for this class was generated from the following file:

- /HElib/include/helib/PAlgebra.h

7.78 helib::MatMul1D Class Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::MatMul1D:



Public Types

- typedef MatMul1DExec ExecType

Public Member Functions

- virtual ∼MatMul1D ()
- virtual const EncryptedArray & getEA () const =0
- virtual long getDim () const =0

7.78.1 Member Typedef Documentation

7.78.1.1 ExecType

```
typedef MatMul1DExec helib::MatMul1D::ExecType
```

7.78.2 Constructor & Destructor Documentation

7.78.2.1 ∼MatMul1D()

```
virtual helib::MatMul1D::~MatMul1D ( ) [inline], [virtual]
```

7.78.3 Member Function Documentation

7.78.3.1 getDim()

```
virtual long helib::MatMul1D::getDim ( ) const [pure virtual]
```

Implemented in helib::MatMulFullHelper< type >, helib::RandomMultiMatrix< type >, and helib::RandomMatrix< type >.

7.78.3.2 getEA()

```
virtual const EncryptedArray& helib::MatMul1D::getEA ( ) const [pure virtual]
```

Implemented in helib::MatMulFullHelper< type >, helib::RandomMultiMatrix< type >, and helib::RandomMatrix< type >.

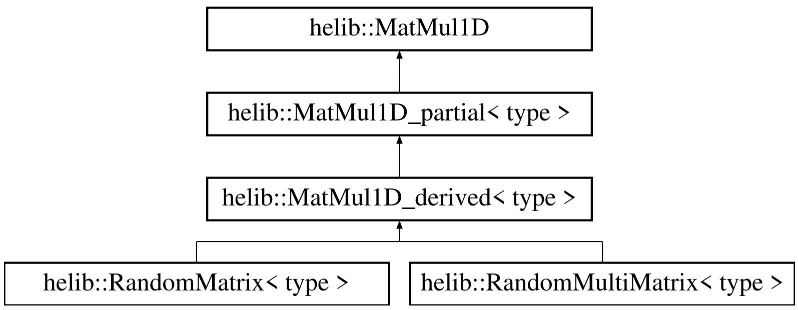
The documentation for this class was generated from the following file:

- /HElib/include/helib/matmul.h

7.79 helib::MatMul1D_derived< type > Class Template Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::MatMul1D_derived< type >:



Public Member Functions

- virtual bool multipleTransforms () const =0
- virtual bool get (RX &out, long i, long j, long k) const =0
- void processDiagonal (RX &poly, long i, const EncryptedArrayDerived< type > &ea) const override

Additional Inherited Members

7.79.1 Member Function Documentation

7.79.1.1 get()

```
template<typename type >
virtual bool helib::MatMul1D_derived< type >::get (
            RX & out,
            long i,
            long j,
            long k ) const  [pure virtual]
```

Implemented in helib::RandomMultiMatrix< type >.

7.79.1.2 multipleTransforms()

```
template<typename type >
virtual bool helib::MatMul1D_derived< type >::multipleTransforms ( ) const  [pure virtual]
```

Implemented in helib::RandomMultiMatrix< type >, and helib::RandomMatrix< type >.

7.79.1.3 processDiagonal()

```
template<typename type >
template void helib::MatMul1D_derived< type >::processDiagonal (
            RX & poly,
            long i,
            const EncryptedArrayDerived< type > & ea ) const  [override], [virtual]
```

Implements helib::MatMul1D_partial< type >.

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

- /HElib/include/helib/matmul.h
- /HElib/src/matmul.cpp

7.80 helib::MatMul1D_derived_impl< type > Struct Template Reference

Static Public Member Functions

- static void processDiagonal1 (RX &poly, long i, const EncryptedArrayDerived< type > &ea, const MatMul1D_derived< type > &mat)
- static void processDiagonal2 (RX &poly, long idx, const EncryptedArrayDerived< type > &ea, const MatMul1D_derived< type > &mat)
- static void processDiagonal (RX &poly, long i, const EncryptedArrayDerived< type > &ea, const MatMul1D_derived< type > &mat)

7.80.1 Member Function Documentation

7.80.1.1 processDiagonal()

```
template<typename type >
static void helib::MatMul1D_derived_impl< type >::processDiagonal (
            RX & poly,
            long i,
            const EncryptedArrayDerived< type > & ea,
            const MatMul1D_derived< type > & mat ) [inline], [static]
```

7.80.1.2 processDiagonal1()

```
template<typename type >
static void helib::MatMul1D_derived_impl< type >::processDiagonal1 (
            RX & poly,
            long i,
            const EncryptedArrayDerived< type > & ea,
            const MatMul1D_derived< type > & mat ) [inline], [static]
```

7.80.1.3 processDiagonal2()

```
template<typename type >
static void helib::MatMul1D_derived_impl< type >::processDiagonal2 (
            RX & poly,
            long idx,
            const EncryptedArrayDerived< type > & ea,
            const MatMul1D_derived< type > & mat ) [inline], [static]
```

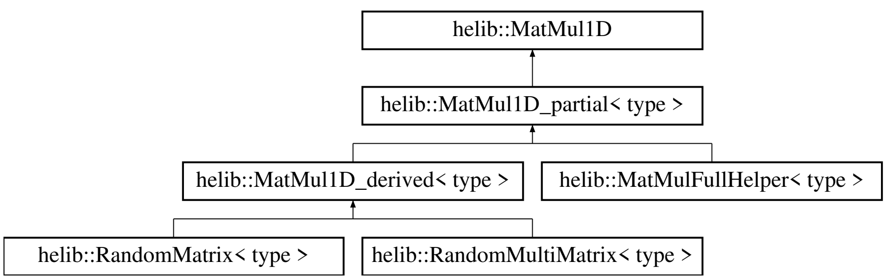
The documentation for this struct was generated from the following file:

- /HElib/src/matmul.cpp

7.81 helib::MatMul1D_partial< type > Class Template Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::MatMul1D_partial< type >:



Public Member Functions

- virtual void processDiagonal (RX &poly, long i, const EncryptedArrayDerived< type > &ea) const =0

Additional Inherited Members

7.81.1 Member Function Documentation

7.81.1.1 processDiagonal()

```
template<typename type >
virtual void helib::MatMul1D_partial< type >::processDiagonal (
            RX & poly,
            long i,
            const EncryptedArrayDerived< type > & ea ) const  [pure virtual]
```

Implemented in helib::MatMul1D_derived< type >, and helib::MatMulFullHelper< type >.

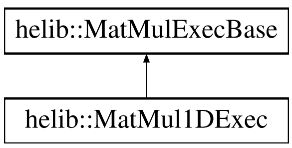
The documentation for this class was generated from the following file:

- /HElib/include/helib/matmul.h

7.82 helib::MatMul1DExec Class Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::MatMul1DExec:



Public Member Functions

- MatMul1DExec (const MatMul1D &mat, bool minimal=false)
- void mul (Ctxt &ctxt) const override
- void upgrade () override
- const EncryptedArray & getEA () const override

Public Attributes

- const EncryptedArray & ea
- long dim
- long D
- bool native
- bool minimal
- long g
- ConstMultiplierCache cache
- ConstMultiplierCache cache1

7.82.1 Constructor & Destructor Documentation

7.82.1.1 MatMul1DExec()

```
helib::MatMul1DExec::MatMul1DExec (
            const MatMul1D & mat,
            bool minimal = false )  [explicit]
```

7.82.2 Member Function Documentation

7.82.2.1 getEA()

```
const EncryptedArray& helib::MatMul1DExec::getEA ( ) const  [inline], [override], [virtual]
```

Implements helib::MatMulExecBase.

7.82.2.2 mul()

```
void helib::MatMul1DExec::mul (
            Ctxt & ctxt ) const  [override], [virtual]
```

Implements helib::MatMulExecBase.

7.82.2.3 upgrade()

```
void helib::MatMul1DExec::upgrade ( )  [inline], [override], [virtual]
```

Implements helib::MatMulExecBase.

7.82.3 Member Data Documentation

7.82.3.1 cache

`ConstMultiplierCache helib::MatMul1DExec::cache`

7.82.3.2 cache1

`ConstMultiplierCache helib::MatMul1DExec::cache1`

7.82.3.3 D

`long helib::MatMul1DExec::D`

7.82.3.4 dim

`long helib::MatMul1DExec::dim`

7.82.3.5 ea

`const EncryptedArray& helib::MatMul1DExec::ea`

7.82.3.6 g

`long helib::MatMul1DExec::g`

7.82.3.7 minimal

`bool helib::MatMul1DExec::minimal`

7.82.3.8 native

```
bool helib::MatMul1DExec::native
```

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

- /HElib/include/helib/matmul.h
- /HElib/src/matmul.cpp

7.83 helib::MatMul1DExec_construct< type > Struct Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, const MatMul1D &mat_basetype, std::vector< std::shared_ptr< ConstMultiplier >> &vec, std::vector< std::shared_ptr< ConstMultiplier >> &vec1, long g)

7.83.1 Member Function Documentation

7.83.1.1 apply()

```
template<typename type >
static void helib::MatMul1DExec_construct< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            const MatMul1D & mat_basetype,
            std::vector< std::shared_ptr< ConstMultiplier >> & vec,
            std::vector< std::shared_ptr< ConstMultiplier >> & vec1,
            long g )  [inline], [static]
```

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

- /HElib/src/matmul.cpp

7.84 helib::MatMulFullExec_construct< type >::MatMulDimComp Struct Reference

Public Member Functions

- MatMulDimComp (const EncryptedArrayDerived< type > *_ea)
- bool operator() (long i, long j)

Public Attributes

- const EncryptedArrayDerived< type > * ea

7.84.1 Constructor & Destructor Documentation

7.84.1.1 MatMulDimComp()

```
template<typename type >
helib::MatMulFullExec_construct< type >::MatMulDimComp::MatMulDimComp (
            const EncryptedArrayDerived< type > * _ea )  [inline]
```

7.84.2 Member Function Documentation

7.84.2.1 operator()()

```
template<typename type >
bool helib::MatMulFullExec_construct< type >::MatMulDimComp::operator() (
            long i,
            long j )  [inline]
```

7.84.3 Member Data Documentation

7.84.3.1 ea

```
template<typename type >
const EncryptedArrayDerived<type>* helib::MatMulFullExec_construct< type >::MatMulDimComp::ea
```

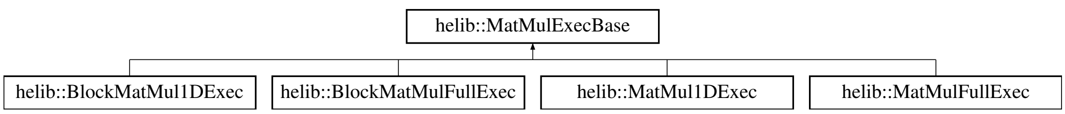
The documentation for this struct was generated from the following file:

- /HElib/src/matmul.cpp

7.85 helib::MatMulExecBase Class Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::MatMulExecBase:



Public Member Functions

- virtual ~MatMulExecBase ()
- virtual const EncryptedArray & getEA () const =0
- virtual void upgrade ()=0
- virtual void mul (Ctxt &ctxt) const =0

7.85.1 Constructor & Destructor Documentation

7.85.1.1 ~MatMulExecBase()

```
virtual helib::MatMulExecBase::~MatMulExecBase ( ) [inline], [virtual]
```

7.85.2 Member Function Documentation

7.85.2.1 getEA()

```
virtual const EncryptedArray& helib::MatMulExecBase::getEA ( ) const [pure virtual]
```

Implemented in helib::BlockMatMulFullExec, helib::MatMulFullExec, helib::BlockMatMul1DExec, and helib::MatMul1DExec.

7.85.2.2 mul()

```
virtual void helib::MatMulExecBase::mul (
            Ctxt & ctxt ) const [pure virtual]
```

Implemented in helib::BlockMatMulFullExec, helib::MatMulFullExec, helib::BlockMatMul1DExec, and helib::MatMul1DExec.

7.85.2.3 upgrade()

```
virtual void helib::MatMulExecBase::upgrade ( ) [pure virtual]
```

Implemented in helib::BlockMatMulFullExec, helib::MatMulFullExec, helib::BlockMatMul1DExec, and helib::MatMul1DExec.

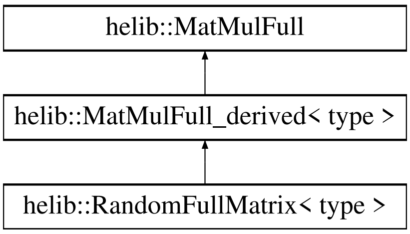
The documentation for this class was generated from the following file:

- /HElib/include/helib/matmul.h

7.86 helib::MatMulFull Class Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::MatMulFull:



Public Types

- typedef MatMulFullExec ExecType

Public Member Functions

- virtual ~MatMulFull ()
- virtual const EncryptedArray & getEA () const =0

7.86.1 Member Typedef Documentation

7.86.1.1 ExecType

```
typedef MatMulFullExec helib::MatMulFull::ExecType
```

7.86.2 Constructor & Destructor Documentation

7.86.2.1 ~MatMulFull()

```
virtual helib::MatMulFull::~MatMulFull ( ) [inline], [virtual]
```

7.86.3 Member Function Documentation

7.86.3.1 getEA()

```
virtual const EncryptedArray& helib::MatMulFull::getEA ( ) const [pure virtual]
```

Implemented in helib::RandomFullMatrix< type >.

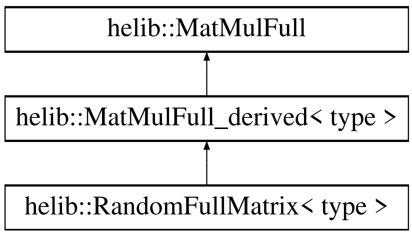
The documentation for this class was generated from the following file:

- /HElib/include/helib/matmul.h

7.87 helib::MatMulFull_derived< type > Class Template Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::MatMulFull_derived< type >:



Public Member Functions

- virtual bool get (RX &out, long i, long j) const =0

Additional Inherited Members

7.87.1 Member Function Documentation

7.87.1.1 get()

```
template<typename type >
virtual bool helib::MatMulFull_derived< type >::get (
            RX & out,
            long i,
            long j ) const [pure virtual]
```

Implemented in helib::RandomFullMatrix< type >.

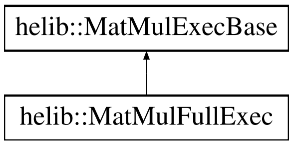
The documentation for this class was generated from the following file:

- /HElib/include/helib/matmul.h

7.88 helib::MatMulFullExec Class Reference

```
#include <matmul.h>
```

Inheritance diagram for helib::MatMulFullExec:



Public Member Functions

- MatMulFullExec (const MatMulFull &mat, bool minimal=false)
- void mul (Ctxt &ctxt) const override
- void upgrade () override
- const EncryptedArray & getEA () const override
- long rec_mul (Ctxt &acc, const Ctxt &ctxt, long dim, long idx) const

Public Attributes

- const EncryptedArray & ea
- bool minimal
- std::vector< long > dims
- std::vector< MatMul1DExec > transforms

7.88.1 Constructor & Destructor Documentation

7.88.1.1 MatMulFullExec()

```
helib::MatMulFullExec::MatMulFullExec (
            const MatMulFull & mat,
            bool minimal = false )   [explicit]
```

7.88.2 Member Function Documentation

7.88.2.1 getEA()

```
const EncryptedArray& helib::MatMulFullExec::getEA ( ) const  [inline], [override], [virtual]
```

Implements helib::MatMulExecBase.

7.88.2.2 mul()

```
void helib::MatMulFullExec::mul (
            Ctxt & ctxt ) const  [override], [virtual]
```

Implements helib::MatMulExecBase.

7.88.2.3 rec_mul()

```
long helib::MatMulFullExec::rec_mul (
            Ctxt & acc,
            const Ctxt & ctxt,
            long dim,
            long idx ) const
```

7.88.2.4 upgrade()

```
void helib::MatMulFullExec::upgrade ( )  [inline], [override], [virtual]
```

Implements helib::MatMulExecBase.

7.88.3 Member Data Documentation

7.88.3.1 dims

```
std::vector<long> helib::MatMulFullExec::dims
```

7.88.3.2 ea

```
const EncryptedArray& helib::MatMulFullExec::ea
```

7.88.3.3 minimal

```
bool helib::MatMulFullExec::minimal
```

7.88.3.4 transforms

```
std::vector<MatMul1DExec> helib::MatMulFullExec::transforms
```

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

- /HElib/include/helib/matmul.h
- /HElib/src/matmul.cpp

7.89 helib::MatMulFullExec_construct< type > Struct Template Reference

Classes

- struct MatMulDimComp

Static Public Member Functions

- static long rec_mul (long dim, long idx, const std::vector< long > &idxes, std::vector< MatMul1DExec > &transforms, bool minimal, const std::vector< long > &dims, const EncryptedArray &ea_basetype, const EncryptedArrayDerived< type > &ea, const MatMulFull_derived< type > &mat)
- static void apply (const EncryptedArrayDerived< type > &ea, const EncryptedArray &ea_basetype, const MatMulFull &mat_basetype, std::vector< MatMul1DExec > &transforms, bool minimal, std::vector< long > &dims)

7.89.1 Member Function Documentation

7.89.1.1 apply()

```
template<typename type >
static void helib::MatMulFullExec_construct< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            const EncryptedArray & ea_basetype,
            const MatMulFull & mat_basetype,
            std::vector< MatMul1DExec > & transforms,
            bool minimal,
            std::vector< long > & dims )  [inline], [static]
```

7.89.1.2 rec_mul()

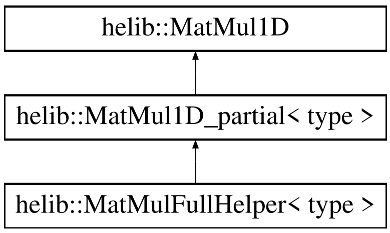
```
template<typename type >
static long helib::MatMulFullExec_construct< type >::rec_mul (
            long dim,
            long idx,
            const std::vector< long > & idxes,
            std::vector< MatMul1DExec > & transforms,
            bool minimal,
            const std::vector< long > & dims,
            const EncryptedArray & ea_basetype,
            const EncryptedArrayDerived< type > & ea,
            const MatMulFull_derived< type > & mat )  [inline], [static]
```

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

- /HElib/src/matmul.cpp

7.90 helib::MatMulFullHelper< type > Class Template Reference

Inheritance diagram for helib::MatMulFullHelper< type >:



Public Member Functions

- MatMulFullHelper (const EncryptedArray &_ea_basetype, const MatMulFull_derived< type > &_mat, const std::vector< long > &_init_idxes, long _dim)
- void processDiagonal (RX &epmat, long offset, const EncryptedArrayDerived< type > &ea) const override
- const EncryptedArray & getEA () const override
- long getDim () const override

Public Attributes

- const EncryptedArray & ea_basetype
- const MatMulFull_derived< type > & mat
- std::vector< long > init_idxes
- long dim

Additional Inherited Members

7.90.1 Constructor & Destructor Documentation

7.90.1.1 MatMulFullHelper()

```
template<typename type >
helib::MatMulFullHelper< type >::MatMulFullHelper (
            const EncryptedArray & _ea_basetype,
            const MatMulFull_derived< type > & _mat,
            const std::vector< long > & _init_idxes,
            long _dim ) [inline]
```

7.90.2 Member Function Documentation

7.90.2.1 getDim()

```
template<typename type >
long helib::MatMulFullHelper< type >::getDim ( ) const [inline], [override], [virtual]
```

Implements helib::MatMul1D.

7.90.2.2 getEA()

```
template<typename type >
const EncryptedArray& helib::MatMulFullHelper< type >::getEA ( ) const [inline], [override],
[virtual]
```

Implements helib::MatMul1D.

7.90.2.3 processDiagonal()

```
template<typename type >
void helib::MatMulFullHelper< type >::processDiagonal (
            RX & epmat,
            long offset,
            const EncryptedArrayDerived< type > & ea ) const [inline], [override], [virtual]
```

Implements helib::MatMul1D_partial< type >.

7.90.3 Member Data Documentation

7.90.3.1 dim

```
template<typename type >
long helib::MatMulFullHelper< type >::dim
```

7.90.3.2 ea_basetype

```
template<typename type >
const EncryptedArray& helib::MatMulFullHelper< type >::ea_basetype
```

7.90.3.3 init_idxes

```
template<typename type >
std::vector<long> helib::MatMulFullHelper< type >::init_idxes
```

7.90.3.4 mat

```
template<typename type >
const MatMulFull_derived<type>& helib::MatMulFullHelper< type >::mat
```

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

- /HElib/src/matmul.cpp

7.91 helib::ModuliSizes Class Reference

A helper class to map required modulo-sizes to primeSets.

```
#include <primeChain.h>
```

Public Types

- typedef std::pair< double, IndexSet > Entry

Public Member Functions

- void init (const std::vector< Cmodulus > &chain, const IndexSet &ctxtPrimes, const IndexSet &smallPrimes)

    initialize helper table for a given chain
- IndexSet getSet4Size (double low, double high, const IndexSet &fromSet, bool reverse) const
- IndexSet getSet4Size (double low, double high, const IndexSet &from1, const IndexSet &from2, bool reverse) const
- void read (std::istream &str)
- void write (std::ostream &str) const

Friends

- std::istream & operator>> (std::istream &s, ModuliSizes &szs)
- std::ostream & operator<< (std::ostream &s, const ModuliSizes &szs)

7.91.1 Detailed Description

A helper class to map required modulo-sizes to primeSets.

7.91.2 Member Typedef Documentation

7.91.2.1 Entry

```
typedef std::pair<double, IndexSet> helib::ModuliSizes::Entry
```

7.91.3 Member Function Documentation

7.91.3.1 getSet4Size() [1/2]

```
IndexSet helib::ModuliSizes::getSet4Size (
            double low,
            double high,
            const IndexSet & from1,
            const IndexSet & from2,
            bool reverse ) const
```

Find a suitable IndexSet of primes whose total size is in the target interval [low,high], trying to minimize the total number of primes dropped from both from1, from2. If no IndexSet exists that fits in the target interval, returns the IndexSet that gives the largest value smaller than low. (or the smallest value greater than low if reverse flag is set).

Find a suitable IndexSet of primes whose total size is in the target interval [low,high], trying to minimize the total number of primes dropped from both from1, from2. If no IndexSet exists that fits in the target interval, returns the IndexSet that gives the largest value smaller than low.

7.91.3.2 getSet4Size() [2/2]

```
IndexSet helib::ModuliSizes::getSet4Size (
            double low,
            double high,
            const IndexSet & fromSet,
            bool reverse ) const
```

Find a suitable IndexSet of primes whose total size is in the target interval [low,high], trying to minimize the number of primes dropped from fromSet. If no IndexSet exists that fits in the target interval, returns the IndexSet that gives the largest value smaller than low (or the smallest value greater than low if reverse flag is set).

7.91.3.3 init()

```
void helib::ModuliSizes::init (
            const std::vector< Cmodulus > & chain,
            const IndexSet & ctxtPrimes,
            const IndexSet & smallPrimes )
```

initialize helper table for a given chain

7.91.3.4 read()

```
void helib::ModuliSizes::read (
            std::istream & str )
```

7.91.3.5 write()

```
void helib::ModuliSizes::write (
            std::ostream & str ) const
```

7.91.4 Friends And Related Function Documentation

7.91.4.1 operator<<

```
std::ostream& operator<< (
            std::ostream & s,
            const ModuliSizes & szs )  [friend]
```

7.91.4.2 operator>>

```
std::istream& operator>> (
            std::istream & s,
            ModuliSizes & szs )  [friend]
```

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

- /HElib/include/helib/primeChain.h
- /HElib/src/primeChain.cpp

7.92 helib::mul_BlockMatMul1D_impl< type > Struct Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, const BlockMatMul1D &mat_basetype)

7.92.1 Member Function Documentation

7.92.1.1 apply()

```
template<typename type >
static void helib::mul_BlockMatMul1D_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            const BlockMatMul1D & mat_basetype ) [inline], [static]
```

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

- /HElib/src/matmul.cpp

7.93 helib::mul_BlockMatMulFull_impl< type > Struct Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, const BlockMatMulFull &mat_basetype)

7.93.1 Member Function Documentation

7.93.1.1 apply()

```
template<typename type >
static void helib::mul_BlockMatMulFull_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            const BlockMatMulFull & mat_basetype ) [inline], [static]
```

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

- /HElib/src/matmul.cpp

7.94 helib::mul_MatMul1D_impl< type > Struct Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, const MatMul1D &mat_↩ basetype)

7.94.1 Member Function Documentation

7.94.1.1 apply()

```
template<typename type >
static void helib::mul_MatMul1D_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            const MatMul1D & mat_basetype )  [inline], [static]
```

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

- /HElib/src/matmul.cpp

7.95 helib::mul_MatMulFull_impl< type > Struct Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, const MatMulFull &mat_↩ basetype)

7.95.1 Member Function Documentation

7.95.1.1 apply()

```
template<typename type >
static void helib::mul_MatMulFull_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            const MatMulFull & mat_basetype )  [inline], [static]
```

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

- /HElib/src/matmul.cpp

7.96 helib::mul_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, const PlaintextArray &other)

7.96.1 Member Function Documentation

7.96.1.1 apply()

```
template<typename type >
static void helib::mul_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            const PlaintextArray & other )  [inline], [static]
```

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

- /HElib/src/EncryptedArray.cpp

7.97 MyClass Class Reference

Public Member Functions

- MyClass (int i)
- int get () const
- void set (int i)

7.97.1 Constructor & Destructor Documentation

7.97.1.1 MyClass()

```
MyClass::MyClass (
            int i )  [inline]
```

7.97.2 Member Function Documentation

7.97.2.1 get()

```
int MyClass::get ( ) const [inline]
```

7.97.2.2 set()

```
void MyClass::set (
            int i ) [inline]
```

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

- /HElib/src/Test_PtrVector.cpp

7.98 helib::negate_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa)

7.98.1 Member Function Documentation

7.98.1.1 apply()

```
template<typename type >
static void helib::negate_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa ) [inline], [static]
```

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

- /HElib/src/EncryptedArray.cpp

7.99 OtherTimingData Class Reference

Public Attributes

- double init2
- double init4
- double keyGen
- double encode2
- double encode2d
- double encode4
- double encode4d
- double encrypt
- double decode2
- double decode4
- double decrypt

7.99.1 Member Data Documentation

7.99.1.1 decode2

`double OtherTimingData::decode2`

7.99.1.2 decode4

`double OtherTimingData::decode4`

7.99.1.3 decrypt

`double OtherTimingData::decrypt`

7.99.1.4 encode2

`double OtherTimingData::encode2`

7.99.1.5 encode2d

`double OtherTimingData::encode2d`

7.99.1.6 encode4

`double OtherTimingData::encode4`

7.99.1.7 encode4d

`double OtherTimingData::encode4d`

7.99.1.8 encrypt

```
double OtherTimingData::encrypt
```

7.99.1.9 init2

```
double OtherTimingData::init2
```

7.99.1.10 init4

```
double OtherTimingData::init4
```

7.99.1.11 keyGen

```
double OtherTimingData::keyGen
```

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

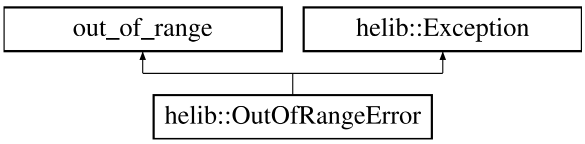
- /HElib/src/Test_Timing.cpp

7.100 helib::OutOfRangeError Class Reference

Inherits from Exception and std::out_of_range.

```
#include <exceptions.h>
```

Inheritance diagram for helib::OutOfRangeError:



Public Member Functions

- OutOfRangeError (const std::string &what_arg)
- OutOfRangeError (const char ∗what_arg)
- virtual ∼OutOfRangeError ()
- virtual const char ∗ what () const noexcept override

Additional Inherited Members

7.100.1 Detailed Description

Inherits from Exception and std::out_of_range.

7.100.2 Constructor & Destructor Documentation

7.100.2.1 OutOfRangeError() [1/2]

```
helib::OutOfRangeError::OutOfRangeError (
            const std::string & what_arg )  [inline], [explicit]
```

7.100.2.2 OutOfRangeError() [2/2]

```
helib::OutOfRangeError::OutOfRangeError (
            const char * what_arg )  [inline], [explicit]
```

7.100.2.3 ∼OutOfRangeError()

```
virtual helib::OutOfRangeError::~OutOfRangeError ( )  [inline], [virtual]
```

7.100.3 Member Function Documentation

7.100.3.1 what()

```
virtual const char* helib::OutOfRangeError::what ( ) const  [inline], [override], [virtual],
[noexcept]
```

Implements helib::Exception.

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

- /HElib/include/helib/exceptions.h

7.101 helib::PAlgebra Class Reference

The structure of (Z/mZ)$*$ /(p)

```
#include <PAlgebra.h>
```

Public Member Functions

- PAlgebra (long mm, long pp=2, const std::vector< long > &_gens=std::vector< long >(), const std::vector< long > &_ords=std::vector< long >())
- bool operator== (const PAlgebra &other) const
- bool operator!= (const PAlgebra &other) const
- void printout () const

  Prints the structure in a readable form.
- void printAll () const
- long getM () const

  Returns m.
- long getP () const

  Returns p.
- long getPhiM () const

  Returns phi(m)
- long getOrdP () const

  The order of p in (Z/mZ)^$*$.
- long getNFactors () const

  The number of distinct prime factors of m.
- long getRadM () const

  getRadM() = prod of distinct prime factors of m
- double getNormBnd () const

  max-norm-on-pwfl-basis <= normBnd $*$ max-norm-canon-embed
- double getPolyNormBnd () const

  max-norm-on-pwfl-basis <= polyNormBnd $*$ max-norm-canon-embed
- long getNSlots () const

  The number of plaintext slots = phi(m)/ord(p)
- long getPow2 () const

  if m = 2^k, then pow2 == k; otherwise, pow2 == 0
- const NTL::ZZX & getPhimX () const

  The cyclotomix polynomial Phi_m(X)
- void set_cM (double c)

  The "ring constant" cM.
- double get_cM () const
- long numOfGens () const

  The prime-power factorization of m.
- long ZmStarGen (long i) const

  the i'th generator in (Z/mZ)^$*$ /(p) (if any)
- long genToPow (long i, long j) const

  the i'th generator to the power j mod m
- long frobeniusPow (long j) const
- long OrderOf (long i) const

  The order of i'th generator (if any)
- long ProdOrdsFrom (long i) const

The product prod_{j=i}^{n-1} OrderOf(i)

- bool SameOrd (long i) const

  Is ord(i'th generator) the same as its order in (Z/mZ)^∗?
- long FrobPerturb (long i) const

Translation between index, representatives, and exponents

- long ith_rep (long i) const

  Returns the i'th element in T.
- long indexOfRep (long t) const

  Returns the index of t in T.
- bool isRep (long t) const

  Is t in T?
- long indexInZmstar (long t) const

  Returns the index of t in (Z/mZ)∗.
- long indexInZmstar_unchecked (long t) const

  Returns the index of t in (Z/mZ)∗ – no range checking.
- long repInZmstar_unchecked (long idx) const

  Returns rep whose index is i.
- bool inZmStar (long t) const
- long exponentiate (const std::vector< long > &exps, bool onlySameOrd=false) const

  Returns prod_i gi^{exps[i]} mod m. If onlySameOrd=true, use only generators that have the same order as in (Z/mZ)^∗.
- long coordinate (long i, long k) const

  Returns coordinate of index k along the i'th dimension.
- std::pair< long, long > breakIndexByDim (long idx, long dim) const
- long assembleIndexByDim (std::pair< long, long > idx, long dim) const

  The inverse of breakIndexByDim.
- long addCoord (long i, long k, long offset) const

  adds offset to index k in the i'th dimension
- bool nextExpVector (std::vector< long > &exps) const
- long fftSizeNeeded () const

  The largest FFT we need to handle degree-m polynomials.
- const PGFFT & getFFTInfo () const
- const half_FFT & getHalfFFTInfo () const
- const quarter_FFT & getQuarterFFTInfo () const

7.101.1 Detailed Description

The structure of (Z/mZ)∗ /(p)

A PAlgebra object is determined by an integer m and a prime p, where p does not divide m. It holds information describing the structure of (Z/mZ)^∗, which is isomorphic to the Galois group over A = Z[X]/Phi_m(X)).

We represent (Z/mZ)^∗ as (Z/mZ)^∗ = (p) x (g1,g2,...) x (h1,h2,...) where the group generated by g1,g2,... consists of the elements that have the same order in (Z/mZ)^∗ as in (Z/mZ)^∗ /(p,g_1,...,g_{i-1}), and h1,h2,... generate the remaining quotient group (Z/mZ)^∗ /(p,g1,g2,...).

We let T subset (Z/mZ)^∗ be a set of representatives for the quotient group (Z/mZ)^∗ /(p), defined as T={ prod_i gi^{ei} ∗ prod_j hj^{ej} } where the ei's range over 0,1,...,ord(gi)-1 and the ej's range over 0,1,...ord(hj)-1 (these last orders are in (Z/mZ)^∗ /(p,g1,g2,...)).

Phi_m(X) is factored as Phi_m(X)= prod_{t in T} F_t(X) mod p, where the F_t's are irreducible modulo p. An arbitrary factor is chosen as F_1, then for each t in T we associate with the index t the factor F_t(X) = GCD(F_1(X^t), Phi↩
_m(X)).

Note that fixing a representation of the field R=(Z/pZ)[X]/F_1(X) and letting z be a root of F_1 in R (which is a primitive m-th root of unity in R), we get that F_t is the minimal polynomial of z^{1/t}.

7.101.2 Constructor & Destructor Documentation

7.101.2.1 PAlgebra()

```
helib::PAlgebra::PAlgebra (
            long mm,
            long pp = 2,
            const std::vector< long > & _gens = std::vector<long>(),
            const std::vector< long > & _ords = std::vector<long>() )
```

7.101.3 Member Function Documentation

7.101.3.1 addCoord()

```
long helib::PAlgebra::addCoord (
            long i,
            long k,
            long offset ) const  [inline]
```

adds offset to index k in the i'th dimension

7.101.3.2 assembleIndexByDim()

```
long helib::PAlgebra::assembleIndexByDim (
            std::pair< long, long > idx,
            long dim ) const  [inline]
```

The inverse of breakIndexByDim.

7.101.3.3 breakIndexByDim()

```
std::pair<long, long> helib::PAlgebra::breakIndexByDim (
            long idx,
            long dim ) const  [inline]
```

Break an index into the hypercube to index of the dimension-dim subcube and index inside that subcube.

7.101.3.4 coordinate()

```
long helib::PAlgebra::coordinate (
            long i,
            long k ) const  [inline]
```

Returns coordinate of index k along the i'th dimension.

7.101.3.5 exponentiate()

```
long helib::PAlgebra::exponentiate (
            const std::vector< long > & exps,
            bool onlySameOrd = false ) const
```

Returns prod_i gi^{exps[i]} mod m. If onlySameOrd=true, use only generators that have the same order as in (Z/mZ)^∗.

7.101.3.6 fftSizeNeeded()

```
long helib::PAlgebra::fftSizeNeeded ( ) const  [inline]
```

The largest FFT we need to handle degree-m polynomials.

7.101.3.7 frobeniusPow()

```
long helib::PAlgebra::frobeniusPow (
            long j ) const
```

7.101.3.8 FrobPerturb()

```
long helib::PAlgebra::FrobPerturb (
            long i ) const  [inline]
```

7.101.3.9 genToPow()

```
long helib::PAlgebra::genToPow (
            long i,
            long j ) const
```

the i'th generator to the power j mod m

7.101.3.10 get_cM()

```
double helib::PAlgebra::get_cM ( ) const [inline]
```

7.101.3.11 getFFTInfo()

```
const PGFFT& helib::PAlgebra::getFFTInfo ( ) const [inline]
```

7.101.3.12 getHalfFFTInfo()

```
const half_FFT& helib::PAlgebra::getHalfFFTInfo ( ) const [inline]
```

7.101.3.13 getM()

```
long helib::PAlgebra::getM ( ) const [inline]
```

Returns m.

7.101.3.14 getNFactors()

```
long helib::PAlgebra::getNFactors ( ) const [inline]
```

The number of distinct prime factors of m.

7.101.3.15 getNormBnd()

```
double helib::PAlgebra::getNormBnd ( ) const [inline]
```

max-norm-on-pwfl-basis $<=$ normBnd $*$ max-norm-canon-embed

7.101.3.16 getNSlots()

```
long helib::PAlgebra::getNSlots ( ) const [inline]
```

The number of plaintext slots = phi(m)/ord(p)

7.101.3.17 getOrdP()

```
long helib::PAlgebra::getOrdP ( ) const  [inline]
```

The order of p in (Z/mZ)^∗.

7.101.3.18 getP()

```
long helib::PAlgebra::getP ( ) const  [inline]
```

Returns p.

7.101.3.19 getPhiM()

```
long helib::PAlgebra::getPhiM ( ) const  [inline]
```

Returns phi(m)

7.101.3.20 getPhimX()

```
const NTL::ZZX& helib::PAlgebra::getPhimX ( ) const  [inline]
```

The cyclotomix polynomial Phi_m(X)

7.101.3.21 getPolyNormBnd()

```
double helib::PAlgebra::getPolyNormBnd ( ) const  [inline]
```

max-norm-on-pwfl-basis <= polyNormBnd ∗ max-norm-canon-embed

7.101.3.22 getPow2()

```
long helib::PAlgebra::getPow2 ( ) const  [inline]
```

if m = 2^k, then pow2 == k; otherwise, pow2 == 0

7.101.3.23 getQuarterFFTInfo()

```
const quarter_FFT& helib::PAlgebra::getQuarterFFTInfo ( ) const [inline]
```

7.101.3.24 getRadM()

```
long helib::PAlgebra::getRadM ( ) const [inline]
```

getRadM() = prod of distinct prime factors of m

7.101.3.25 indexInZmstar()

```
long helib::PAlgebra::indexInZmstar (
            long t ) const [inline]
```

Returns the index of t in (Z/mZ)∗.

7.101.3.26 indexInZmstar_unchecked()

```
long helib::PAlgebra::indexInZmstar_unchecked (
            long t ) const [inline]
```

Returns the index of t in (Z/mZ)∗ – no range checking.

7.101.3.27 indexOfRep()

```
long helib::PAlgebra::indexOfRep (
            long t ) const [inline]
```

Returns the index of t in T.

7.101.3.28 inZmStar()

```
bool helib::PAlgebra::inZmStar (
            long t ) const [inline]
```

7.101.3.29 isRep()

```
bool helib::PAlgebra::isRep (
            long t ) const  [inline]
```

Is t in T?

7.101.3.30 ith_rep()

```
long helib::PAlgebra::ith_rep (
            long i ) const  [inline]
```

Returns the i'th element in T.

7.101.3.31 nextExpVector()

```
bool helib::PAlgebra::nextExpVector (
            std::vector< long > & exps ) const  [inline]
```

exps is an array of exponents (the dLog of some t in T), this function increment exps lexicographic order, return false if it cannot be incremented (because it is at its maximum value)

7.101.3.32 numOfGens()

```
long helib::PAlgebra::numOfGens ( ) const  [inline]
```

The prime-power factorization of m.

The number of generators in (Z/mZ)^$*$ /(p)

7.101.3.33 operator"!=()

```
bool helib::PAlgebra::operator!= (
            const PAlgebra & other ) const  [inline]
```

7.101.3.34 operator==()

```
bool helib::PAlgebra::operator== (
            const PAlgebra & other ) const
```

7.101.3.35 OrderOf()

```
long helib::PAlgebra::OrderOf (
            long i ) const  [inline]
```

The order of i'th generator (if any)

7.101.3.36 printAll()

```
void helib::PAlgebra::printAll ( ) const
```

7.101.3.37 printout()

```
void helib::PAlgebra::printout ( ) const
```

Prints the structure in a readable form.

7.101.3.38 ProdOrdsFrom()

```
long helib::PAlgebra::ProdOrdsFrom (
            long i ) const  [inline]
```

The product prod_{j=i}^{n-1} OrderOf(i)

7.101.3.39 repInZmstar_unchecked()

```
long helib::PAlgebra::repInZmstar_unchecked (
            long idx ) const  [inline]
```

Returns rep whose index is i.

7.101.3.40 SameOrd()

```
bool helib::PAlgebra::SameOrd (
            long i ) const  [inline]
```

Is ord(i'th generator) the same as its order in (Z/mZ)^∗?

7.101.3.41 set_cM()

```
void helib::PAlgebra::set_cM (
            double c ) [inline]
```

The "ring constant" cM.

7.101.3.42 ZmStarGen()

```
long helib::PAlgebra::ZmStarGen (
            long i ) const [inline]
```

the i'th generator in (Z/mZ)^∗ /(p) (if any)

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

- /HElib/include/helib/PAlgebra.h
- /HElib/src/PAlgebra.cpp

7.102 helib::PAlgebraMod Class Reference

The structure of Z[X]/(Phi_m(X), p)

`#include <PAlgebra.h>`

Public Member Functions

- PAlgebraMod (const PAlgebra &zMStar, long r)
- template<typename type >
  const PAlgebraModDerived< type > & getDerived (type) const
- const PAlgebraModCx & getCx () const
- bool operator== (const PAlgebraMod &other) const
- bool operator!= (const PAlgebraMod &other) const
- PA_tag getTag () const

  Returns the type tag: PA_GF2_tag or PA_zz_p_tag.
- const PAlgebra & getZMStar () const

  Returns reference to underlying PAlgebra object.
- const std::vector< NTL::ZZX > & getFactorsOverZZ () const

  Returns reference to the factorization of Phi_m(X) mod p^r, but as ZZX's.
- long getR () const

  The value r.
- long getPPowR () const

  The value p^r.
- void restoreContext () const

  Restores the NTL context for p^r.
- zzX getMask_zzX (long i, long j) const

7.102.1 Detailed Description

The structure of Z[X]/(Phi_m(X), p)

An object of type PAlgebraMod stores information about a PAlgebra object zMStar, and an integer r. It also provides support for encoding and decoding plaintext slots.

the PAlgebra object zMStar defines $(Z/mZ)^\wedge * /(0)$, and the PAlgebraMod object stores various tables related to the polynomial ring Z/(p^r)[X]. To do this most efficiently, if p == 2 and r == 1, then these polynomials are represented as GF2X's, and otherwise as zz_pX's. Thus, the types of these objects are not determined until run time. As such, we need to use a class hierarchy, as follows.

- PAlgebraModBase is a virtual class
- PAlgebraModDerived<type> is a derived template class, where type is either PA_GF2 or PA_zz_p.
- The class PAlgebraMod is a simple wrapper around a smart pointer to a PAlgebraModBase object: copying a PAlgebra object results is a "deep copy" of the underlying object of the derived class. It provides dDirect access to the virtual methods of PAlgebraModBase, along with a "downcast" operator to get a reference to the object as a derived type, and also == and != operators.

7.102.2 Constructor & Destructor Documentation

7.102.2.1 PAlgebraMod()

```
helib::PAlgebraMod::PAlgebraMod (
            const PAlgebra & zMStar,
            long r ) [inline], [explicit]
```

7.102.3 Member Function Documentation

7.102.3.1 getCx()

```
const PAlgebraModCx& helib::PAlgebraMod::getCx ( ) const [inline]
```

7.102.3.2 getDerived()

```
template<typename type >
const PAlgebraModDerived<type>& helib::PAlgebraMod::getDerived (
            type ) const [inline]
```

Downcast operator example: const PAlgebraModDerived<PA_GF2>& rep = alMod.getDerived(PA_GF2());

7.102.3.3 getFactorsOverZZ()

```
const std::vector<NTL::ZZX>& helib::PAlgebraMod::getFactorsOverZZ ( ) const  [inline]
```

Returns reference to the factorization of Phi_m(X) mod p^r, but as ZZX's.

7.102.3.4 getMask_zzX()

```
zzX helib::PAlgebraMod::getMask_zzX (
             long i,
             long j ) const  [inline]
```

7.102.3.5 getPPowR()

```
long helib::PAlgebraMod::getPPowR ( ) const  [inline]
```

The value p^r.

7.102.3.6 getR()

```
long helib::PAlgebraMod::getR ( ) const  [inline]
```

The value r.

7.102.3.7 getTag()

```
PA_tag helib::PAlgebraMod::getTag ( ) const  [inline]
```

Returns the type tag: PA_GF2_tag or PA_zz_p_tag.

7.102.3.8 getZMStar()

```
const PAlgebra& helib::PAlgebraMod::getZMStar ( ) const  [inline]
```

Returns reference to underlying PAlgebra object.

7.102.3.9 operator"!=()

```
bool helib::PAlgebraMod::operator!= (
            const PAlgebraMod & other ) const  [inline]
```

7.102.3.10 operator==()

```
bool helib::PAlgebraMod::operator== (
            const PAlgebraMod & other ) const  [inline]
```

7.102.3.11 restoreContext()

```
void helib::PAlgebraMod::restoreContext ( ) const  [inline]
```

Restores the NTL context for p^r.

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

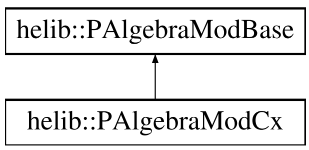
- /HElib/include/helib/PAlgebra.h

7.103 helib::PAlgebraModBase Class Reference

Virtual base class for PAlgebraMod.

```
#include <PAlgebra.h>
```

Inheritance diagram for helib::PAlgebraModBase:



Public Member Functions

- virtual ∼PAlgebraModBase ()
- virtual PAlgebraModBase ∗ clone () const =0
- virtual PA_tag getTag () const =0

  Returns the type tag: PA_GF2_tag or PA_zz_p_tag.
- virtual const PAlgebra & getZMStar () const =0

  Returns reference to underlying PAlgebra object.
- virtual const std::vector< NTL::ZZX > & getFactorsOverZZ () const =0

  Returns reference to the factorization of Phi_m(X) mod p^r, but as ZZX's.
- virtual long getR () const =0

  The value r.
- virtual long getPPowR () const =0

  The value p^r.
- virtual void restoreContext () const =0

  Restores the NTL context for p^r.
- virtual zzX getMask_zzX (long i, long j) const =0

7.103.1 Detailed Description

Virtual base class for PAlgebraMod.

7.103.2 Constructor & Destructor Documentation

7.103.2.1 ~PAlgebraModBase()

```
virtual helib::PAlgebraModBase::~PAlgebraModBase ( ) [inline], [virtual]
```

7.103.3 Member Function Documentation

7.103.3.1 clone()

```
virtual PAlgebraModBase* helib::PAlgebraModBase::clone ( ) const [pure virtual]
```

Implemented in helib::PAlgebraModCx.

7.103.3.2 getFactorsOverZZ()

```
virtual const std::vector<NTL::ZZX>& helib::PAlgebraModBase::getFactorsOverZZ ( ) const [pure
virtual]
```

Returns reference to the factorization of Phi_m(X) mod p^r, but as ZZX's.

Implemented in helib::PAlgebraModCx.

7.103.3.3 getMask_zzX()

```
virtual zzX helib::PAlgebraModBase::getMask_zzX (
            long i,
            long j ) const [pure virtual]
```

7.103.3.4 getPPowR()

`virtual long helib::PAlgebraModBase::getPPowR ( ) const [pure virtual]`

The value p^r.

Implemented in helib::PAlgebraModCx.

7.103.3.5 getR()

`virtual long helib::PAlgebraModBase::getR ( ) const [pure virtual]`

The value r.

Implemented in helib::PAlgebraModCx.

7.103.3.6 getTag()

`virtual PA_tag helib::PAlgebraModBase::getTag ( ) const [pure virtual]`

Returns the type tag: PA_GF2_tag or PA_zz_p_tag.

Implemented in helib::PAlgebraModCx.

7.103.3.7 getZMStar()

`virtual const PAlgebra& helib::PAlgebraModBase::getZMStar ( ) const [pure virtual]`

Returns reference to underlying PAlgebra object.

Implemented in helib::PAlgebraModCx.

7.103.3.8 restoreContext()

`virtual void helib::PAlgebraModBase::restoreContext ( ) const [pure virtual]`

Restores the NTL context for p^r.

Implemented in helib::PAlgebraModCx.

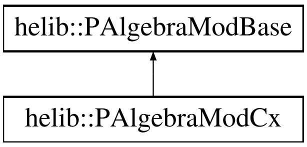
The documentation for this class was generated from the following file:

- /HElib/include/helib/PAlgebra.h

7.104 helib::PAlgebraModCx Class Reference

```
#include <PAlgebra.h>
```

Inheritance diagram for helib::PAlgebraModCx:



Public Member Functions

- PAlgebraModCx (const PAlgebra &palg, long _r)
- PAlgebraModBase * clone () const override
- PA_tag getTag () const override

  Returns the type tag: PA_GF2_tag or PA_zz_p_tag.
- const PAlgebra & getZMStar () const override

  Returns reference to underlying PAlgebra object.
- long getR () const override

  The value r.
- long getPPowR () const override

  The value p^r.
- void restoreContext () const override

  Restores the NTL context for p^r.
- const std::vector< NTL::ZZX > & getFactorsOverZZ () const override

  Returns reference to the factorization of Phi_m(X) mod p^r, but as ZZX's.
- zzX getMask_zzX (UNUSED long i, UNUSED long j) const override

7.104.1 Detailed Description

A different derived class to be used for the approximate-numbers scheme This is mostly a dummy class, but needed since the context always has a PAlgebraMod data member.

7.104.2 Constructor & Destructor Documentation

7.104.2.1 PAlgebraModCx()

```
helib::PAlgebraModCx::PAlgebraModCx (
            const PAlgebra & palg,
            long _r )  [inline]
```

7.104.3 Member Function Documentation

7.104.3.1 clone()

```
PAlgebraModBase* helib::PAlgebraModCx::clone ( ) const  [inline], [override], [virtual]
```

Implements helib::PAlgebraModBase.

7.104.3.2 getFactorsOverZZ()

```
const std::vector<NTL::ZZX>& helib::PAlgebraModCx::getFactorsOverZZ ( ) const  [inline], [override],
[virtual]
```

Returns reference to the factorization of Phi_m(X) mod p^r, but as ZZX's.

Implements helib::PAlgebraModBase.

7.104.3.3 getMask_zzX()

```
zzX helib::PAlgebraModCx::getMask_zzX (
            UNUSED long i,
            UNUSED long j ) const  [inline], [override]
```

7.104.3.4 getPPowR()

```
long helib::PAlgebraModCx::getPPowR ( ) const  [inline], [override], [virtual]
```

The value p^r.

Implements helib::PAlgebraModBase.

7.104.3.5 getR()

```
long helib::PAlgebraModCx::getR ( ) const  [inline], [override], [virtual]
```

The value r.

Implements helib::PAlgebraModBase.

7.104.3.6 getTag()

```
PA_tag helib::PAlgebraModCx::getTag ( ) const  [inline], [override], [virtual]
```

Returns the type tag: PA_GF2_tag or PA_zz_p_tag.

Implements helib::PAlgebraModBase.

7.104.3.7 getZMStar()

```
const PAlgebra& helib::PAlgebraModCx::getZMStar ( ) const  [inline], [override], [virtual]
```

Returns reference to underlying PAlgebra object.

Implements helib::PAlgebraModBase.

7.104.3.8 restoreContext()

```
void helib::PAlgebraModCx::restoreContext ( ) const  [inline], [override], [virtual]
```

Restores the NTL context for p^r.

Implements helib::PAlgebraModBase.

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

- /HElib/include/helib/PAlgebra.h

7.105 helib::PAlgebraModDerived< type > Class Template Reference

A concrete instantiation of the virtual class.

```
#include <PAlgebra.h>
```

Public Member Functions

- PAlgebraModDerived (const PAlgebra &zMStar, long r)
- PAlgebraModDerived (const PAlgebraModDerived &other)
- PAlgebraModDerived & operator= (const PAlgebraModDerived &other)
- virtual PAlgebraModBase ∗ clone () const override

    Returns a pointer to a "clone".
- virtual PA_tag getTag () const override

    Returns the type tag: PA_GF2_tag or PA_zz_p_tag.
- virtual const PAlgebra & getZMStar () const override

    Returns reference to underlying PAlgebra object.
- virtual const std::vector< NTL::ZZX > & getFactorsOverZZ () const override

    Returns reference to the factorization of Phi_m(X) mod p^r, but as ZZX's.
- virtual long getR () const override

    The value r.
- virtual long getPPowR () const override

    The value p^r.
- virtual void restoreContext () const override

    Restores the NTL context for p^r.
- const RXModulus & getPhimXMod () const

    Returns reference to an RXModulus representing Phi_m(X) (mod p^r)
- const vec_RX & getFactors () const

    Returns reference to the factors of Phim_m(X) modulo p^r.
- const vec_RX & getCrtCoeffs () const

    Returns the CRT coefficients: element i contains (prod_{j!=i} F_j)^{-1} mod F_i, where F_0 F_1 ... is the factorization of Phi_m(X) mod p^r.
- const std::vector< std::vector< RX > > & getMaskTable () const

    Returns ref to maskTable, which is used to implement rotations (in the EncryptedArray module).
- zzX getMask_zzX (long i, long j) const override

Embedding in the plaintext slots and decoding back

In all the functions below, G must be irreducible mod p, and the order of G must divide the order of p modulo m (as returned by zMStar.getOrdP()). In addition, when r > 1, G must be the monomial X (RX(1, 1))

- void CRT_decompose (std::vector< RX > &crt, const RX &H) const

    Returns a std::vector crt[] such that crt[i] = H mod Ft (with t = T[i])
- void CRT_reconstruct (RX &H, std::vector< RX > &crt) const

    Returns H in R[X]/Phi_m(X) s.t. for every i<nSlots and t=T[i], we have H == crt[i] (mod Ft)
- void mapToSlots (MappingData< type > &mappingData, const RX &G) const

    Compute the maps for all the slots. In the current implementation, we if r > 1, then we must have either deg(G) == 1 or G == factors[0].
- void embedInAllSlots (RX &H, const RX &alpha, const MappingData< type > &mappingData) const

    Returns H in R[X]/Phi_m(X) s.t. for every t in T, the element Ht = (H mod Ft) in R[X]/Ft(X) represents the same element as alpha in R[X]/G(X).
- void embedInSlots (RX &H, const std::vector< RX > &alphas, const MappingData< type > &mapping↩ Data) const

    Returns H in R[X]/Phi_m(X) s.t. for every t in T, the element Ht = (H mod Ft) in R[X]/Ft(X) represents the same element as alphas[i] in R[X]/G(X).
- void decodePlaintext (std::vector< RX > &alphas, const RX &ptxt, const MappingData< type > &mappingData) const

    Return an array such that alphas[i] in R[X]/G(X) represent the same element as rt = (H mod Ft) in R[X]/Ft(X) where t=T[i].
- void buildLinPolyCoeffs (std::vector< RX > &C, const std::vector< RX > &L, const MappingData< type > &mappingData) const

    Returns a coefficient std::vector C for the linearized polynomial representing M.

7.105.1 Detailed Description

template<typename type>
class helib::PAlgebraModDerived< type >

A concrete instantiation of the virtual class.

7.105.2 Constructor & Destructor Documentation

7.105.2.1 PAlgebraModDerived() [1/2]

```
template<typename type >
helib::PAlgebraModDerived< type >::PAlgebraModDerived (
            const PAlgebra & zMStar,
            long r )
```

7.105.2.2 PAlgebraModDerived() [2/2]

```
template<typename type >
helib::PAlgebraModDerived< type >::PAlgebraModDerived (
            const PAlgebraModDerived< type > & other )  [inline]
```

7.105.3 Member Function Documentation

7.105.3.1 buildLinPolyCoeffs()

```
template<typename type >
void helib::PAlgebraModDerived< type >::buildLinPolyCoeffs (
            std::vector< RX > & C,
            const std::vector< RX > & L,
            const MappingData< type > & mappingData ) const
```

Returns a coefficient std::vector C for the linearized polynomial representing M.

For h in Z/(p^r)[X] of degree $<$ d,

$$M(h(X) mod G) = sum_{i=0}^{d-1}(C[j] mod G) * (h(X^{p^j}) mod G).$$

G is assumed to be defined in mappingData, with d = deg(G). L describes a linear map M by describing its action on the standard power basis: M(x^j mod G) = (L[j] mod G), for j = 0..d-1.

7.105.3.2 clone()

```
template<typename type >
virtual PAlgebraModBase* helib::PAlgebraModDerived< type >::clone ( ) const [inline], [override],
[virtual]
```

Returns a pointer to a "clone".

7.105.3.3 CRT_decompose()

```
template<typename type >
void helib::PAlgebraModDerived< type >::CRT_decompose (
            std::vector< RX > & crt,
            const RX & H ) const
```

Returns a std::vector crt[] such that crt[i] = H mod Ft (with t = T[i])

7.105.3.4 CRT_reconstruct()

```
template<typename type >
void helib::PAlgebraModDerived< type >::CRT_reconstruct (
            RX & H,
            std::vector< RX > & crt ) const
```

Returns H in R[X]/Phi_m(X) s.t. for every i<nSlots and t=T[i], we have H == crt[i] (mod Ft)

7.105.3.5 decodePlaintext()

```
template<typename type >
void helib::PAlgebraModDerived< type >::decodePlaintext (
            std::vector< RX > & alphas,
            const RX & ptxt,
            const MappingData< type > & mappingData ) const
```

Return an array such that alphas[i] in R[X]/G(X) represent the same element as rt = (H mod Ft) in R[X]/Ft(X) where t=T[i].

The mappingData argument should contain the output of mapToSlots(G).

7.105.3.6 embedInAllSlots()

```
template<typename type >
void helib::PAlgebraModDerived< type >::embedInAllSlots (
            RX & H,
            const RX & alpha,
            const MappingData< type > & mappingData ) const
```

Returns H in R[X]/Phi_m(X) s.t. for every t in T, the element Ht = (H mod Ft) in R[X]/Ft(X) represents the same element as alpha in R[X]/G(X).

Must have deg(alpha)<deg(G). The mappingData argument should contain the output of mapToSlots(G).

7.105.3.7 embedInSlots()

```
template<typename type >
void helib::PAlgebraModDerived< type >::embedInSlots (
            RX & H,
            const std::vector< RX > & alphas,
            const MappingData< type > & mappingData ) const
```

Returns H in R[X]/Phi_m(X) s.t. for every t in T, the element Ht = (H mod Ft) in R[X]/Ft(X) represents the same element as alphas[i] in R[X]/G(X).

Must have deg(alpha[i])<deg(G). The mappingData argument should contain the output of mapToSlots(G).

7.105.3.8 getCrtCoeffs()

```
template<typename type >
const vec_RX& helib::PAlgebraModDerived< type >::getCrtCoeffs ( ) const [inline]
```

Returns the CRT coefficients: element i contains (prod_{j!=i} F_j)^{-1} mod F_i, where F_0 F_1 ... is the factorization of Phi_m(X) mod p^r.

7.105.3.9 getFactors()

```
template<typename type >
const vec_RX& helib::PAlgebraModDerived< type >::getFactors ( ) const [inline]
```

Returns reference to the factors of Phim_m(X) modulo p^r.

7.105.3.10 getFactorsOverZZ()

```
template<typename type >
virtual const std::vector<NTL::ZZX>& helib::PAlgebraModDerived< type >::getFactorsOverZZ ( )
const [inline], [override], [virtual]
```

Returns reference to the factorization of Phi_m(X) mod p^r, but as ZZX's.

7.105.3.11 getMask_zzX()

```
template<typename type >
zzX helib::PAlgebraModDerived< type >::getMask_zzX (
            long i,
            long j ) const [inline], [override]
```

7.105.3.12 getMaskTable()

```
template<typename type >
const std::vector<std::vector<RX> >& helib::PAlgebraModDerived< type >::getMaskTable ( )
const [inline]
```

Returns ref to maskTable, which is used to implement rotations (in the EncryptedArray module).

`maskTable[i][j]` is a polynomial representation of a mask that is 1 in all slots whose i'th coordinate is at least j, and 0 elsewhere. We have:

```
maskTable.size() == zMStar.numOfGens()      // # of generators
for i = 0..maskTable.size()-1:
  maskTable[i].size() == zMStar.OrderOf(i)+1 // order of generator i
```

7.105.3.13 getPhimXMod()

```
template<typename type >
const RXModulus& helib::PAlgebraModDerived< type >::getPhimXMod ( ) const [inline]
```

Returns reference to an RXModulus representing Phi_m(X) (mod p^r)

7.105.3.14 getPPowR()

```
template<typename type >
virtual long helib::PAlgebraModDerived< type >::getPPowR ( ) const [inline], [override],
[virtual]
```

The value p^r.

7.105.3.15 getR()

```
template<typename type >
virtual long helib::PAlgebraModDerived< type >::getR ( ) const [inline], [override], [virtual]
```

The value r.

7.105.3.16 getTag()

```
template<typename type >
virtual PA_tag helib::PAlgebraModDerived< type >::getTag ( ) const [inline], [override],
[virtual]
```

Returns the type tag: PA_GF2_tag or PA_zz_p_tag.

7.105.3.17 getZMStar()

```
template<typename type >
virtual const PAlgebra& helib::PAlgebraModDerived< type >::getZMStar ( ) const  [inline],
[override], [virtual]
```

Returns reference to underlying PAlgebra object.

7.105.3.18 mapToSlots()

```
template<typename type >
void helib::PAlgebraModDerived< type >::mapToSlots (
            MappingData< type > & mappingData,
            const RX & G ) const
```

Compute the maps for all the slots. In the current implementation, we if r > 1, then we must have either deg(G) == 1 or G == factors[0].

7.105.3.19 operator=()

```
template<typename type >
PAlgebraModDerived& helib::PAlgebraModDerived< type >::operator= (
            const PAlgebraModDerived< type > & other )  [inline]
```

7.105.3.20 restoreContext()

```
template<typename type >
virtual void helib::PAlgebraModDerived< type >::restoreContext ( ) const  [inline], [override],
[virtual]
```

Restores the NTL context for p^r.

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

- /HElib/include/helib/PAlgebra.h
- /HElib/src/PAlgebra.cpp

7.106 helib::PermNetLayer Class Reference

The information needed to apply one layer of a permutation network.

```
#include <permutations.h>
```

Public Member Functions

- long getGenIdx () const
- long getE () const
- const NTL::Vec< long > & getShifts () const
- bool isIdentity () const

Friends

- class PermNetwork
- std::ostream & operator<< (std::ostream &s, const PermNetwork &net)

7.106.1 Detailed Description

The information needed to apply one layer of a permutation network.

7.106.2 Member Function Documentation

7.106.2.1 getE()

```
long helib::PermNetLayer::getE ( ) const  [inline]
```

7.106.2.2 getGenIdx()

```
long helib::PermNetLayer::getGenIdx ( ) const  [inline]
```

7.106.2.3 getShifts()

```
const NTL::Vec<long>& helib::PermNetLayer::getShifts ( ) const  [inline]
```

7.106.2.4 isIdentity()

```
bool helib::PermNetLayer::isIdentity ( ) const  [inline]
```

7.106.3 Friends And Related Function Documentation

7.106.3.1 operator<<

```
std::ostream& operator<< (
            std::ostream & s,
            const PermNetwork & net )  [friend]
```

7.106.3.2 PermNetwork

```
friend class PermNetwork  [friend]
```

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

- /HElib/include/helib/permutations.h

7.107 helib::PermNetwork Class Reference

A full permutation network.

```
#include <permutations.h>
```

Public Member Functions

- PermNetwork ()
- PermNetwork (const Permut &pi, const GeneratorTrees &trees)
- long depth () const
- void buildNetwork (const Permut &pi, const GeneratorTrees &trees)
- void applyToCtxt (Ctxt &c, const EncryptedArray &ea) const

  Apply network to permute a ciphertext.
- void applyToCube (HyperCube< long > &v) const

  Apply network to array, used mostly for debugging.
- void applyToPtxt (NTL::ZZX &p, const EncryptedArray &ea) const

  Apply network to plaintext polynomial, used mostly for debugging.
- const PermNetLayer & getLayer (long i) const

Friends

- std::ostream & operator<< (std::ostream &s, const PermNetwork &net)

7.107.1 Detailed Description

A full permutation network.

7.107.2 Constructor & Destructor Documentation

7.107.2.1 PermNetwork() [1/2]

```
helib::PermNetwork::PermNetwork ( )  [inline]
```

7.107.2.2 PermNetwork() [2/2]

```
helib::PermNetwork::PermNetwork (
            const Permut & pi,
            const GeneratorTrees & trees )  [inline]
```

7.107.3 Member Function Documentation

7.107.3.1 applyToCtxt()

```
void helib::PermNetwork::applyToCtxt (
            Ctxt & c,
            const EncryptedArray & ea ) const
```

Apply network to permute a ciphertext.

7.107.3.2 applyToCube()

```
void helib::PermNetwork::applyToCube (
            HyperCube< long > & v ) const
```

Apply network to array, used mostly for debugging.

7.107.3.3 applyToPtxt()

```
void helib::PermNetwork::applyToPtxt (
            NTL::ZZX & p,
            const EncryptedArray & ea ) const
```

Apply network to plaintext polynomial, used mostly for debugging.

7.107.3.4 buildNetwork()

```
void helib::PermNetwork::buildNetwork (
            const Permut & pi,
            const GeneratorTrees & trees )
```

Take as input a permutation pi and the trees of all the generators, and prepares the permutation network for this pi

7.107.3.5 depth()

```
long helib::PermNetwork::depth ( ) const  [inline]
```

7.107.3.6 getLayer()

```
const PermNetLayer& helib::PermNetwork::getLayer (
            long i ) const  [inline]
```

7.107.4 Friends And Related Function Documentation

7.107.4.1 operator<<

```
std::ostream& operator<< (
            std::ostream & s,
            const PermNetwork & net )  [friend]
```

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

- /HElib/include/helib/permutations.h
- /HElib/src/PermNetwork.cpp

7.108 helib::PGFFT Class Reference

```
#include <PGFFT.h>
```

Classes

- class aligned_allocator

Public Types

- template<class T >
  using aligned_vector = std::vector< T, aligned_allocator< T > >

Public Member Functions

- PGFFT (long n)
- void apply (const std::complex< double > *src, std::complex< double > *dst) const
- void apply (std::complex< double > *v) const
- PGFFT (const PGFFT &)=delete
- PGFFT (PGFFT &&)=delete
- PGFFT & operator= (const PGFFT &)=delete
- PGFFT & operator= (PGFFT &&)=delete

Static Public Member Functions

- static bool simd_enabled ()
- static void * aligned_allocate (std::size_t n, std::size_t nelts)
- static void aligned_deallocate (void *p)

7.108.1 Member Typedef Documentation

7.108.1.1 aligned_vector

```
template<class T >
using helib::PGFFT::aligned_vector = std::vector<T,aligned_allocator<T> >
```

7.108.2 Constructor & Destructor Documentation

7.108.2.1 PGFFT() [1/3]

```
helib::PGFFT::PGFFT (
            long n )  [explicit]
```

7.108.2.2 PGFFT() [2/3]

```
helib::PGFFT::PGFFT (
            const PGFFT & )  [delete]
```

7.108.2.3 PGFFT() [3/3]

```
helib::PGFFT::PGFFT (
            PGFFT && )  [delete]
```

7.108.3 Member Function Documentation

7.108.3.1 aligned_allocate()

```
void * helib::PGFFT::aligned_allocate (
            std::size_t n,
            std::size_t nelts ) [static]
```

7.108.3.2 aligned_deallocate()

```
void helib::PGFFT::aligned_deallocate (
            void * p ) [static]
```

7.108.3.3 apply() [1/2]

```
void helib::PGFFT::apply (
            const std::complex< double > * src,
            std::complex< double > * dst ) const
```

7.108.3.4 apply() [2/2]

```
void helib::PGFFT::apply (
            std::complex< double > * v ) const [inline]
```

7.108.3.5 operator=() [1/2]

```
PGFFT& helib::PGFFT::operator= (
            const PGFFT & ) [delete]
```

7.108.3.6 operator=() [2/2]

```
PGFFT& helib::PGFFT::operator= (
            PGFFT && ) [delete]
```

7.108.3.7 simd_enabled()

```
bool helib::PGFFT::simd_enabled ( )  [static]
```

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

- /HElib/include/helib/PGFFT.h
- /HElib/src/PGFFT.cpp

7.109 helib::PlaintextArray Class Reference

```
#include <EncryptedArray.h>
```

Public Member Functions

- PlaintextArray (const EncryptedArray &ea)
- PlaintextArray (const PlaintextArray &other)
- PlaintextArray & operator= (const PlaintextArray &other)
- template< typename type >
  std::vector< typename type::RX > & getData ()
- template< typename type >
  const std::vector< typename type::RX > & getData () const
- void print (std::ostream &s) const

7.109.1 Constructor & Destructor Documentation

7.109.1.1 PlaintextArray() [1/2]

```
helib::PlaintextArray::PlaintextArray (
            const EncryptedArray & ea )  [inline]
```

7.109.1.2 PlaintextArray() [2/2]

```
helib::PlaintextArray::PlaintextArray (
            const PlaintextArray & other )  [inline]
```

7.109.2 Member Function Documentation

7.109.2.1 getData() [1/2]

```
template<typename type >
std::vector<typename type::RX>& helib::PlaintextArray::getData ( )  [inline]
```

7.109.2.2 getData() [2/2]

```
template<typename type >
const std::vector<typename type::RX>& helib::PlaintextArray::getData ( ) const  [inline]
```

7.109.2.3 operator=()

```
PlaintextArray& helib::PlaintextArray::operator= (
            const PlaintextArray & other )  [inline]
```

7.109.2.4 print()

```
void helib::PlaintextArray::print (
            std::ostream & s ) const  [inline]
```

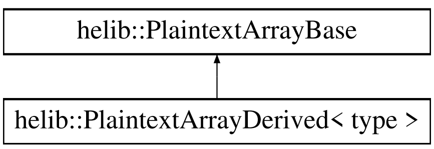
The documentation for this class was generated from the following file:

- /HElib/include/helib/EncryptedArray.h

7.110 helib::PlaintextArrayBase Class Reference

```
#include <EncryptedArray.h>
```

Inheritance diagram for helib::PlaintextArrayBase:



Public Member Functions

- virtual ~PlaintextArrayBase ()
- virtual void print (std::ostream &s) const =0

7.110.1 Constructor & Destructor Documentation

7.110.1.1 ∼PlaintextArrayBase()

```
virtual helib::PlaintextArrayBase::∼PlaintextArrayBase ( ) [inline], [virtual]
```

7.110.2 Member Function Documentation

7.110.2.1 print()

```
virtual void helib::PlaintextArrayBase::print (
            std::ostream & s ) const [pure virtual]
```

Implemented in helib::PlaintextArrayDerived< type >.

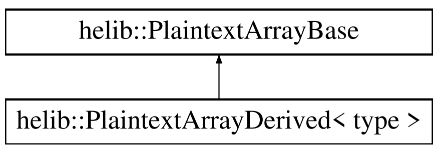
The documentation for this class was generated from the following file:

- /HElib/include/helib/EncryptedArray.h

7.111 helib::PlaintextArrayDerived< type > Class Template Reference

```
#include <EncryptedArray.h>
```

Inheritance diagram for helib::PlaintextArrayDerived< type >:



Public Member Functions

- virtual void print (std::ostream &s) const

Public Attributes

- std::vector< RX > data

7.111.1 Member Function Documentation

7.111.1.1 print()

```
template<typename type >
virtual void helib::PlaintextArrayDerived< type >::print (
            std::ostream & s ) const  [inline], [virtual]
```

Implements helib::PlaintextArrayBase.

7.111.2 Member Data Documentation

7.111.2.1 data

```
template<typename type >
std::vector<RX> helib::PlaintextArrayDerived< type >::data
```

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

- /HElib/include/helib/EncryptedArray.h

7.112 helib::PolyMod Class Reference

An object that contains an `NTL::ZZX` polynomial along with a coefficient modulus `p2r` and a polynomial modulus `G`.

`#include <PolyMod.h>`

Public Member Functions

- PolyMod ()

  Default constructor.
- PolyMod (const std::shared_ptr< PolyModRing > &ringDescriptor)

  No-data constructor.
- PolyMod (long input, const std::shared_ptr< PolyModRing > &ringDescriptor)

  Constant constructor.
- PolyMod (const std::vector< long > &input, const std::shared_ptr< PolyModRing > &ringDescriptor)

  Coefficient vector constructor.
- PolyMod (const NTL::ZZX &input, const std::shared_ptr< PolyModRing > &ringDescriptor)

  Polynomial constructor.
- PolyMod (const PolyMod &input)=default

  Default copy constructor.

- PolyMod (PolyMod &&input) noexcept=default

  Default move constructor.
- ∼PolyMod ()=default

  Default destructor.
- PolyMod & operator= (const PolyMod &input)=default

  Assignment operator.
- PolyMod & operator= (PolyMod &&input)=default

  default move assignment operator
- PolyMod & operator= (long input)

  `long` *assignment operator, creates a constant polynomial mod G and p2r.*
- PolyMod & operator= (const std::vector< long > &input)

  `std::vector<long>` *assignment operator, creates a polynomial mod G and p2r.*
- PolyMod & operator= (const std::initializer_list< long > &input)

  `std::initializer_list<long>` *assignment operator, creates a polynomial mod G and p2r.*
- PolyMod & operator= (const NTL::ZZX &input)

  `NTL::ZZX` *assignment operator, creates a polynomial mod G and p2r.*
- operator long () const

  Explicit conversion to a `long`*.*
- operator std::vector< long > () const

  Explicit conversion to `std::vector<long>` *(coefficient vector).*
- operator NTL::ZZX () const

  Explicit conversion to an `NTL::ZZX`*.*
- bool isValid () const

  Gets the validity of `this`*. This will be* `false` *iff* `this` *was default constructed.*
- long getp2r () const

  Get current p^r value.
- NTL::ZZX getG () const

  Get current G value.
- NTL::ZZX getData () const

  Getter function that returns the data of `PolyMod` *as an* `NTL::ZZX`*.*
- bool operator== (const PolyMod &rhs) const

  Equals operator between two `PolyMod` *objects.*
- bool operator== (long rhs) const

  Equals operator between a `PolyMod` *and a* `long`*.*
- bool operator== (const std::vector< long > &rhs) const

  Equals operator between two `PolyMod` *objects.*
- bool operator== (const NTL::ZZX &rhs) const

  Equals operator between two `PolyMod` *objects.*
- template<typename T >
  bool operator!= (T &&rhs) const

  Not equals operator.
- PolyMod & negate ()

  Negate function.
- PolyMod operator- () const

  Unary minus operator.
- PolyMod operator* (const PolyMod &rhs) const

  Infix multiplication operator.
- PolyMod operator* (long rhs) const

  Infix multiplication operator with `long`*.*
- PolyMod operator* (const NTL::ZZX &rhs) const

  Infix multiplication operator with `NTL::ZZX`*.*

- PolyMod operator+ (const PolyMod &rhs) const

  Infix plus operator.
- PolyMod operator+ (long rhs) const

  Infix plus operator with `long`.
- PolyMod operator+ (const NTL::ZZX &rhs) const

  Infix plus operator with `NTL::ZZX`.
- PolyMod operator- (const PolyMod &rhs) const

  Infix minus operator.
- PolyMod operator- (long rhs) const

  Infix minus operator with `long`.
- PolyMod operator- (const NTL::ZZX &rhs) const

  Infix minus operator with `NTL::ZZX`.
- PolyMod & operator*= (const PolyMod &otherPoly)

  Times equals operator with `PolyMod` *rhs.*
- PolyMod & operator*= (long scalar)

  Times equals operator with `long` *rhs.*
- PolyMod & operator*= (const NTL::ZZX &otherPoly)

  Times equals operator with `NTL::ZZX` *rhs.*
- PolyMod & operator+= (const PolyMod &otherPoly)

  Plus equals operator with `PolyMod` *rhs.*
- PolyMod & operator+= (long scalar)

  Plus equals operator with `long` *rhs.*
- PolyMod & operator+= (const NTL::ZZX &otherPoly)

  Plus equals operator with `NTL::ZZX` *rhs.*
- PolyMod & operator-= (const PolyMod &otherPoly)

  Minus equals operator with `PolyMod` *rhs.*
- PolyMod & operator-= (long scalar)

  Minus equals operator with `long` *rhs.*
- PolyMod & operator-= (const NTL::ZZX &otherPoly)

  Minus equals operator with `NTL::ZZX` *rhs.*

Friends

- std::istream & operator>> (std::istream &is, PolyMod &poly)

  Input shift operator.
- std::ostream & operator<< (std::ostream &os, const PolyMod &poly)

  Output shift operator.

7.112.1 Detailed Description

An object that contains an `NTL::ZZX` polynomial along with a coefficient modulus `p2r` and a polynomial modulus `G`.

A `PolyMod` object can be considered to be an element of $\mathbb{Z}_{p^r}[x]/G$ where p^r and G are the passed-in parameters `p2r` and `G`.

This allows for inter-`PolyMod` operations with the modulo operations performed automatically.

General usage:

```
helib::PolyMod poly(input_data, p2r, G);
```

Calling an operation on a default constructed `PolyMod` will throw an `helib::LogicError`.

7.112.2 Constructor & Destructor Documentation

7.112.2.1 PolyMod() [1/7]

```
helib::PolyMod::PolyMod ( )
```

Default constructor.

Note

PolyMod objects constructed using this are marked as invalid. If used for any operation whether directly on a PolyMod or via another object such as Ptxt this will produce an error.

7.112.2.2 PolyMod() [2/7]

```
helib::PolyMod::PolyMod (
            const std::shared_ptr< PolyModRing > & ringDescriptor )  [explicit]
```

No-data constructor.

Parameters

ringDescriptor	Descriptor object for the plaintext ring. Contains p^r and G which are to be used for modular reduction.

Note

This constructor does not take in input data but can be assigned data later via `operator=`.

7.112.2.3 PolyMod() [3/7]

```
helib::PolyMod::PolyMod (
            long input,
            const std::shared_ptr< PolyModRing > & ringDescriptor )
```

Constant constructor.

Parameters

input	Input data as a `long`.
ringDescriptor	Descriptor object for the plaintext ring. Contains p^r and G which are to be used for modular reduction.

Note

This constructor accepts input data as a `long` and converts it into an `NTL::ZZX` polynomial.

7.112.2.4 PolyMod() [4/7]

```
helib::PolyMod::PolyMod (
            const std::vector< long > & input,
            const std::shared_ptr< PolyModRing > & ringDescriptor )
```

Coefficient vector constructor.

Parameters

input	Input data as a vector of `long` (the i'th element of the vector corresponds to the coefficient of x^i).
ringDescriptor	Descriptor object for the plaintext ring. Contains p^r and G which are to be used for modular reduction.

Note

This constructor accepts input data as a `std::vector<long>` and converts it into an `NTL::ZZX` polynomial.

7.112.2.5 PolyMod() [5/7]

```
helib::PolyMod::PolyMod (
            const NTL::ZZX & input,
            const std::shared_ptr< PolyModRing > & ringDescriptor )
```

Polynomial constructor.

Parameters

input	Input data as an `NTL::ZZX`.
ringDescriptor	Descriptor object for the plaintext ring. Contains p^r and G which are to be used for modular reduction.

Note

This constructor accepts input data as an `NTL::ZZX`.

7.112.2.6 PolyMod() [6/7]

```
helib::PolyMod::PolyMod (
            const PolyMod & input )  [default]
```

Default copy constructor.

Parameters

input	`PolyMod` object that is copied.

7.112.2.7 PolyMod() [7/7]

```
helib::PolyMod::PolyMod (
            PolyMod && input )  [default], [noexcept]
```

Default move constructor.

7.112.2.8 ∼PolyMod()

`helib::PolyMod::~PolyMod ( ) [default]`

Default destructor.

7.112.3 Member Function Documentation

7.112.3.1 getData()

`NTL::ZZX helib::PolyMod::getData ( ) const`

Getter function that returns the data of `PolyMod` as an `NTL::ZZX`.

7.112.3.2 getG()

`NTL::ZZX helib::PolyMod::getG ( ) const`

Get current G value.

Returns

The current G value in use.

7.112.3.3 getp2r()

`long helib::PolyMod::getp2r ( ) const`

Get current p^r value.

Returns

The current p^r value in use.

7.112.3.4 isValid()

```
bool helib::PolyMod::isValid ( ) const
```

Gets the validity of `this`. This will be `false` iff `this` was default constructed.

Returns

`true` if `this` is valid, `false` otherwise.

7.112.3.5 negate()

```
PolyMod & helib::PolyMod::negate ( )
```

Negate function.

Returns

Reference to `*this` post negation.

7.112.3.6 operator long()

```
helib::PolyMod::operator long ( ) const [explicit]
```

Explicit conversion to a `long`.

Note

This function returns only the constant term even if the polynomial contains higher order terms.

7.112.3.7 operator NTL::ZZX()

```
helib::PolyMod::operator NTL::ZZX ( ) const [explicit]
```

Explicit conversion to an `NTL::ZZX`.

7.112.3.8 operator std::vector< long >()

```
helib::PolyMod::operator std::vector< long > ( ) const [explicit]
```

Explicit conversion to `std::vector<long>` (coefficient vector).

7.112.3.9 operator"!=()

```
template<typename T >
bool helib::PolyMod::operator!= (
            T && rhs ) const [inline]
```

Not equals operator.

Parameters

rhs	Right-hand side of comparison.

Returns

`true` if not equal, `false` otherwise

Note

Simply forwards to the correct `operator==` method.

7.112.3.10 operator*() [1/3]

```
PolyMod helib::PolyMod::operator* (
            const NTL::ZZX & rhs ) const
```

Infix multiplication operator with `NTL::ZZX`.

Parameters

rhs	Right hand side of multiplication.

Returns

Product of the two objects.

7.112.3.11 operator*() [2/3]

```
PolyMod helib::PolyMod::operator* (
            const PolyMod & rhs ) const
```

Infix multiplication operator.

Parameters

rhs	Right hand side of multiplication.

Returns

Product of the two PolyMod objects.

7.112.3.12 operator*() [3/3]

```
PolyMod helib::PolyMod::operator* (
            long rhs ) const
```

Infix multiplication operator with `long`.

Parameters

rhs	Right hand side of multiplication.

Returns

Product of the two values.

7.112.3.13 operator*=() [1/3]

```
PolyMod & helib::PolyMod::operator*= (
            const NTL::ZZX & otherPoly )
```

Times equals operator with `NTL::ZZX` rhs.

Parameters

otherPoly	Right hand side of multiplication.

Returns

Reference to `*this` post multiplication.

7.112.3.14 operator*=() [2/3]

```
PolyMod & helib::PolyMod::operator*= (
            const PolyMod & otherPoly )
```

Times equals operator with `PolyMod` rhs.

Parameters

otherPoly	Right hand side of multiplication.

Returns

Reference to `*this` post multiplication.

7.112.3.15 operator*=() [3/3]

```
PolyMod & helib::PolyMod::operator*= (
            long scalar )
```

Times equals operator with `long` rhs.

Parameters

scalar	Right hand side of multiplication.

Returns

Reference to `*this` post multiplication.

7.112.3.16 operator+() [1/3]

```
PolyMod helib::PolyMod::operator+ (
             const NTL::ZZX & rhs ) const
```

Infix plus operator with `NTL::ZZX`.

Parameters

rhs	Right hand side of addition.

Returns

Sum of the two objects.

7.112.3.17 operator+() [2/3]

```
PolyMod helib::PolyMod::operator+ (
             const PolyMod & rhs ) const
```

Infix plus operator.

Parameters

rhs	Right hand side of addition.

Returns

Sum of the two `PolyMod` objects.

7.112.3.18 operator+() [3/3]

```
PolyMod helib::PolyMod::operator+ (
             long rhs ) const
```

Infix plus operator with `long`.

Parameters

rhs	Right hand side of addition.

Returns

Sum of the two values.

7.112.3.19 operator+=() [1/3]

```
PolyMod & helib::PolyMod::operator+= (
            const NTL::ZZX & otherPoly )
```

Plus equals operator with `NTL::ZZX` rhs.

Parameters

otherPoly	Right hand side of addition.

Returns

Reference to `*this` post addition.

7.112.3.20 operator+=() [2/3]

```
PolyMod & helib::PolyMod::operator+= (
            const PolyMod & otherPoly )
```

Plus equals operator with `PolyMod` rhs.

Parameters

otherPoly	Right hand side of addition.

Returns

Reference to `*this` post addition.

7.112.3.21 operator+=() [3/3]

```
PolyMod & helib::PolyMod::operator+= (
            long scalar )
```

Plus equals operator with `long` rhs.

Parameters

scalar	Right hand side of addition.

Returns

Reference to `*this` post addition.

7.112.3.22 operator-() [1/4]

```
PolyMod helib::PolyMod::operator- ( ) const
```

Unary minus operator.

Returns

Negation of the `PolyMod`.

7.112.3.23 operator-() [2/4]

```
PolyMod helib::PolyMod::operator- (
            const NTL::ZZX & rhs ) const
```

Infix minus operator with `NTL::ZZX`.

Parameters

rhs	Right hand side of subtraction.

Returns

Difference of the two objects.

7.112.3.24 operator-() [3/4]

```
PolyMod helib::PolyMod::operator- (
            const PolyMod & rhs ) const
```

Infix minus operator.

Parameters

rhs	Right hand side of subtraction.

Returns

Difference of the two `PolyMod` objects.

7.112.3.25 operator-() [4/4]

```
PolyMod helib::PolyMod::operator- (
            long rhs ) const
```

Infix minus operator with `long`.

Parameters

rhs	Right hand side of subtraction.

Returns

Difference of the two values.

7.112.3.26 operator-=() [1/3]

```
PolyMod & helib::PolyMod::operator-= (
            const NTL::ZZX & otherPoly )
```

Minus equals operator with `NTL::ZZX` rhs.

Parameters

otherPoly	Right hand side of subtraction.

Returns

Reference to `*this` post subtraction.

7.112.3.27 operator-=() [2/3]

```
PolyMod & helib::PolyMod::operator-= (
            const PolyMod & otherPoly )
```

Minus equals operator with `PolyMod` rhs.

Parameters

otherPoly	Right hand side of subtraction.

Returns

Reference to `*this` post subtraction.

7.112.3.28 operator-=() [3/3]

```
PolyMod & helib::PolyMod::operator-= (
            long scalar )
```

Minus equals operator with `long` rhs.

Parameters

scalar	Right hand side of subtraction.

Returns

Reference to `*this` post subtraction.

7.112.3.29 operator=() [1/6]

```
PolyMod & helib::PolyMod::operator= (
            const NTL::ZZX & input )
```

`NTL::ZZX` assignment operator, creates a polynomial mod G and p2r.

Parameters

input	Polynomial.

7.112.3.30 operator=() [2/6]

```
PolyMod& helib::PolyMod::operator= (
            const PolyMod & input )  [default]
```

Assignment operator.

Parameters

input	Another `PolyMod` to copy.

7.112.3.31 operator=() [3/6]

```
PolyMod & helib::PolyMod::operator= (
            const std::initializer_list< long > & input )
```

`std::initializer_list<long>` assignment operator, creates a polynomial mod G and p2r.

Parameters

input	coefficient vector as an initializer list of `long` (the i'th element of the vector corresponds to the coefficient of x^i).

7.112.3.32 operator=() [4/6]

```
PolyMod & helib::PolyMod::operator= (
            const std::vector< long > & input )
```

`std::vector<long>` assignment operator, creates a polynomial mod G and p2r.

Parameters

input	Coefficient vector of `long` (the i'th element of the vector corresponds to the coefficient of x^i).

7.112.3.33 operator=() [5/6]

```
PolyMod & helib::PolyMod::operator= (
            long input )
```

`long` assignment operator, creates a constant polynomial mod G and p2r.

Parameters

input	`long` datum.

7.112.3.34 operator=() [6/6]

```
PolyMod& helib::PolyMod::operator= (
            PolyMod && input ) [default]
```

default move assignment operator

7.112.3.35 operator==() [1/4]

```
bool helib::PolyMod::operator== (
            const NTL::ZZX & rhs ) const
```

Equals operator between two `PolyMod` objects.

Parameters

rhs	Other `PolyMod` to compare to.

Returns

`true` if identical, `false` otherwise.

Note

Always returns false when called on invalid `PolyMod` objects.

7.112.3.36 operator==() [2/4]

```
bool helib::PolyMod::operator== (
            const PolyMod & rhs ) const
```

Equals operator between two PolyMod objects.

Parameters

rhs	Other PolyMod to compare to.

Returns

true if PolyMod objects are identical, false otherwise.

7.112.3.37 operator==() [3/4]

```
bool helib::PolyMod::operator== (
            const std::vector< long > & rhs ) const
```

Equals operator between two PolyMod objects.

Parameters

rhs	Other PolyMod to compare to.

Returns

true if identical, false otherwise.

Note

Always returns false when called on invalid PolyMod objects.

7.112.3.38 operator==() [4/4]

```
bool helib::PolyMod::operator== (
            long rhs ) const
```

Equals operator between a PolyMod and a long.

Parameters

rhs	`long` to compare the data against.

Returns

`true` if identical, `false` otherwise.

Note

Always returns false when called on invalid `PolyMod` objects.

7.112.4 Friends And Related Function Documentation

7.112.4.1 operator<<

```
std::ostream& operator<< (
            std::ostream & os,
            const PolyMod & poly ) [friend]
```

Output shift operator.

Parameters

os	Output `std::ostream`.
poly	`PolyMod` object to be written.

Returns

Input `std::ostream` post writing.

Note

p2r and G are not serialised, see note of `operator>>`.

7.112.4.2 operator>>

```
std::istream& operator>> (
            std::istream & is,
            PolyMod & poly ) [friend]
```

Input shift operator.

Parameters

is	Input std::istream.
poly	Destination PolyMod object.

Returns

Input `std::istream` post reading.

Note

`poly` must be constructed with an appropriate p2r and G **BEFORE** calling this function. For example,

```
PolyMod my_poly(p2r, G);
std::cin » my_poly;
```

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

- /HElib/include/helib/PolyMod.h
- /HElib/src/PolyMod.cpp

7.113 helib::PolyModRing Struct Reference

Lightweight type for describing the structure of a single slot of the plaintext space.

`#include <PolyModRing.h>`

Public Member Functions

- PolyModRing ()=delete
- PolyModRing & operator= (const PolyModRing &)=delete
- PolyModRing & operator= (PolyModRing &&)=delete
- PolyModRing (const PolyModRing &other)=default

    Copy constructor.
- PolyModRing (PolyModRing &&other)=default

    Move constructor.
- ∼PolyModRing ()=default

    Destructor.
- PolyModRing (long p, long r, const NTL::ZZX &G)

    Constructor.
- bool operator== (const PolyModRing &rhs) const noexcept

    Equality operator.
- bool operator!= (const PolyModRing &rhs) const noexcept

    Not-equals operator.

Public Attributes

- const long p

  The characteristic of the plaintext space. This should be prime.
- const long r

  The power of p used in the plaintext space coefficient modulus.
- const NTL::ZZX G

  The irreducible factor of Phi_m(X) used for the algebra of the individual slots.
- const long p2r

  The plaintext space coefficient modulus, equal to p^r.

Friends

- std::ostream & operator<< (std::ostream &os, const PolyModRing &ring)

  Output shift operator.

7.113.1 Detailed Description

Lightweight type for describing the structure of a single slot of the plaintext space.

A single slot of the plaintext space is isomorphic to $\mathbb{Z}[X]/(G(x), p^r)$ for some irreducible factor G of $\Phi_m(X)$, so the main useful members of this `struct` are `p`, `r`, `G`, and `p2r`.

The fields of this `struct` are all `const`, so they should be determined at the time of construction.

Note

This `struct` aggregates this often-useful information into a single placeholder for convenience.

7.113.2 Constructor & Destructor Documentation

7.113.2.1 PolyModRing() [1/4]

```
helib::PolyModRing::PolyModRing ( )  [delete]
```

7.113.2.2 PolyModRing() [2/4]

```
helib::PolyModRing::PolyModRing (
            const PolyModRing & other )  [default]
```

Copy constructor.

7.113.2.3 PolyModRing() [3/4]

```
helib::PolyModRing::PolyModRing (
            PolyModRing && other )  [default]
```

Move constructor.

7.113.2.4 ∼PolyModRing()

```
helib::PolyModRing::∼PolyModRing ( )  [default]
```

Destructor.

7.113.2.5 PolyModRing() [4/4]

```
helib::PolyModRing::PolyModRing (
            long p,
            long r,
            const NTL::ZZX & G )
```

Constructor.

Parameters

p	The characteristic of the plaintext space.
r	The power of p used in the plaintext space coefficient modulus.

Parameters

G	The irreducible factor of Phi↩ _m(X) used for the algebra of the individual slots.

p^r will be calculated automatically.

Note

p should be a prime number.

7.113.3 Member Function Documentation

7.113.3.1 operator"!=()

```
bool helib::PolyModRing::operator!= (
            const PolyModRing & rhs ) const  [noexcept]
```

Not-equals operator.

7.113.3.2 operator=() [1/2]

```
PolyModRing& helib::PolyModRing::operator= (
            const PolyModRing & )  [delete]
```

7.113.3.3 operator=() [2/2]

```
PolyModRing& helib::PolyModRing::operator= (
            PolyModRing && )  [delete]
```

7.113.3.4 operator==()

```
bool helib::PolyModRing::operator== (
            const PolyModRing & rhs ) const  [noexcept]
```

Equality operator.

7.113.4 Friends And Related Function Documentation

7.113.4.1 operator<<

```
std::ostream& operator<< (
            std::ostream & os,
            const PolyModRing & ring )  [friend]
```

Output shift operator.

Parameters

os	Output `std::ostream`.
ring	`PolyModRing` object to be written.

Returns

Input `std::ostream` post writing.

7.113.5 Member Data Documentation

7.113.5.1 G

```
const NTL::ZZX helib::PolyModRing::G
```

The irreducible factor of Phi_m(X) used for the algebra of the individual slots.

7.113.5.2 p

`const long helib::PolyModRing::p`

The characteristic of the plaintext space. This should be prime.

7.113.5.3 p2r

`const long helib::PolyModRing::p2r`

The plaintext space coefficient modulus, equal to p^r.

7.113.5.4 r

`const long helib::PolyModRing::r`

The power of p used in the plaintext space coefficient modulus.

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

- /HElib/include/helib/PolyModRing.h
- /HElib/src/PolyModRing.cpp

7.114 helib::PowerfulConversion Class Reference

Conversion between powerful representation in R_m/(q) and zz_pX.

`#include <powerful.h>`

Public Member Functions

- PowerfulConversion ()
- PowerfulConversion (const PowerfulTranslationIndexes &ind)
- void initPConv (const PowerfulTranslationIndexes &ind)
- void restoreModulus () const
- const CubeSignature & getLongSig () const
- const CubeSignature & getShortSig () const
- long powerfulToPoly (NTL::zz_pX &poly, const HyperCube< NTL::zz_p > &powerful) const
- long polyToPowerful (HyperCube< NTL::zz_p > &powerful, const NTL::zz_pX &poly) const

7.114.1 Detailed Description

Conversion between powerful representation in R_m/(q) and zz_pX.

Usage pattern is as follows:

// compute tables for index translation PowerfulTranslationIndexes ind(mvec); // mvec is some factorization of m

// ... set the current zz_p::modulus to something before initializing PowerfulConversion pConv(ind);

// Alternatively use // PowerfulConversion pConv(); pConv.initPConv(ind); // Only the latter call needs zz_p::modulus to be defined

// A powerful basis is defined wrt same modulus and cube signature HyperCube<zz_p> powerful(pConv.get↩ShortSig());

// ... some code here to initialize powerful // code can also do other stuff, perhaps changing zz_p::modulus

pConv.restoreModulus(); // restore zz_p::modulus zz_pX poly; // defined relative to the same modulus pConv.↩powerfulToPoly(poly, powerful);

// ... some more code here, perhaps changing zz_p::modulus again

pConv.restoreModulus(); // restore zz_p::modulus pConv.polyToPowerful(powerful, poly);

7.114.2 Constructor & Destructor Documentation

7.114.2.1 PowerfulConversion() [1/2]

```
helib::PowerfulConversion::PowerfulConversion ( )  [inline]
```

7.114.2.2 PowerfulConversion() [2/2]

```
helib::PowerfulConversion::PowerfulConversion (
            const PowerfulTranslationIndexes & ind )  [inline], [explicit]
```

7.114.3 Member Function Documentation

7.114.3.1 getLongSig()

```
const CubeSignature& helib::PowerfulConversion::getLongSig ( ) const  [inline]
```

7.114.3.2 getShortSig()

```
const CubeSignature& helib::PowerfulConversion::getShortSig ( ) const  [inline]
```

7.114.3.3 initPConv()

```
void helib::PowerfulConversion::initPConv (
            const PowerfulTranslationIndexes & ind )  [inline]
```

7.114.3.4 polyToPowerful()

```
long helib::PowerfulConversion::polyToPowerful (
            HyperCube< NTL::zz_p > & powerful,
            const NTL::zz_pX & poly ) const
```

7.114.3.5 powerfulToPoly()

```
long helib::PowerfulConversion::powerfulToPoly (
            NTL::zz_pX & poly,
            const HyperCube< NTL::zz_p > & powerful ) const
```

The conversion routines return the value of the modulus q. It is assumed that the modulus is already set before calling them

7.114.3.6 restoreModulus()

```
void helib::PowerfulConversion::restoreModulus ( ) const  [inline]
```

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

- /HElib/include/helib/powerful.h
- /HElib/src/powerful.cpp

7.115 helib::PowerfulDCRT Class Reference

Conversion between powerful representation, DoubleCRT, and ZZX.

```
#include <powerful.h>
```

Public Member Functions

- PowerfulDCRT (const Context &_context, const NTL::Vec< long > &mvec)
- const PowerfulTranslationIndexes & getIndexTranslation () const
- const PowerfulConversion & getPConv (long i) const
- void dcrtToPowerful (NTL::Vec< NTL::ZZ > &powerful, const DoubleCRT &dcrt) const
- void ZZXtoPowerful (NTL::Vec< NTL::ZZ > &powerful, const NTL::ZZX &poly) const
- void powerfulToZZX (NTL::ZZX &poly, const NTL::Vec< NTL::ZZ > &powerful) const

7.115.1 Detailed Description

Conversion between powerful representation, DoubleCRT, and ZZX.

7.115.2 Constructor & Destructor Documentation

7.115.2.1 PowerfulDCRT()

```
helib::PowerfulDCRT::PowerfulDCRT (
            const Context & _context,
            const NTL::Vec< long > & mvec )
```

7.115.3 Member Function Documentation

7.115.3.1 dcrtToPowerful()

```
void helib::PowerfulDCRT::dcrtToPowerful (
            NTL::Vec< NTL::ZZ > & powerful,
            const DoubleCRT & dcrt ) const
```

7.115.3.2 getIndexTranslation()

```
const PowerfulTranslationIndexes& helib::PowerfulDCRT::getIndexTranslation ( ) const [inline]
```

7.115.3.3 getPConv()

```
const PowerfulConversion& helib::PowerfulDCRT::getPConv (
            long i ) const [inline]
```

7.115.3.4 powerfulToZZX()

```
void helib::PowerfulDCRT::powerfulToZZX (
            NTL::ZZX & poly,
            const NTL::Vec< NTL::ZZ > & powerful ) const
```

7.115.3.5 ZZXtoPowerful()

```
void helib::PowerfulDCRT::ZZXtoPowerful (
            NTL::Vec< NTL::ZZ > & powerful,
            const NTL::ZZX & poly ) const
```

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

- /HElib/include/helib/powerful.h
- /HElib/src/powerful.cpp

7.116 helib::PowerfulTranslationIndexes Class Reference

Holds index tables for translation between powerful and zz_pX.

`#include <powerful.h>`

Public Member Functions

- PowerfulTranslationIndexes (const NTL::Vec< long > &mv)

Public Attributes

- long m
- long phim
- NTL::Vec< long > mvec
- NTL::Vec< long > phivec
- NTL::Vec< long > divvec
- NTL::Vec< long > invvec
- CubeSignature longSig
- CubeSignature shortSig
- NTL::Vec< long > polyToCubeMap
- NTL::Vec< long > cubeToPolyMap
- NTL::Vec< long > shortToLongMap
- NTL::Vec< NTL::ZZX > cycVec
- NTL::ZZX phimX

7.116.1 Detailed Description

Holds index tables for translation between powerful and zz_pX.

7.116.2 Constructor & Destructor Documentation

7.116.2.1 PowerfulTranslationIndexes()

```
helib::PowerfulTranslationIndexes::PowerfulTranslationIndexes (
            const NTL::Vec< long > & mv )
```

7.116.3 Member Data Documentation

7.116.3.1 cubeToPolyMap

```
NTL::Vec<long> helib::PowerfulTranslationIndexes::cubeToPolyMap
```

7.116.3.2 cycVec

```
NTL::Vec<NTL::ZZX> helib::PowerfulTranslationIndexes::cycVec
```

7.116.3.3 divvec

```
NTL::Vec<long> helib::PowerfulTranslationIndexes::divvec
```

7.116.3.4 invvec

```
NTL::Vec<long> helib::PowerfulTranslationIndexes::invvec
```

7.116.3.5 longSig

```
CubeSignature helib::PowerfulTranslationIndexes::longSig
```

7.116.3.6 m

```
long helib::PowerfulTranslationIndexes::m
```

7.116.3.7 mvec

```
NTL::Vec<long> helib::PowerfulTranslationIndexes::mvec
```

7.116.3.8 phim

```
long helib::PowerfulTranslationIndexes::phim
```

7.116.3.9 phimX

```
NTL::ZZX helib::PowerfulTranslationIndexes::phimX
```

7.116.3.10 phivec

```
NTL::Vec<long> helib::PowerfulTranslationIndexes::phivec
```

7.116.3.11 polyToCubeMap

```
NTL::Vec<long> helib::PowerfulTranslationIndexes::polyToCubeMap
```

7.116.3.12 shortSig

```
CubeSignature helib::PowerfulTranslationIndexes::shortSig
```

7.116.3.13 shortToLongMap

```
NTL::Vec<long> helib::PowerfulTranslationIndexes::shortToLongMap
```

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

- /HElib/include/helib/powerful.h
- /HElib/src/powerful.cpp

7.117 helib::PrimeGenerator Struct Reference

Public Member Functions

- PrimeGenerator (long _len, long _m)
- long next ()

Public Attributes

- long len
- long m
- long k
- long t

7.117.1 Constructor & Destructor Documentation

7.117.1.1 PrimeGenerator()

```
helib::PrimeGenerator::PrimeGenerator (
            long _len,
            long _m )  [inline]
```

7.117.2 Member Function Documentation

7.117.2.1 next()

```
long helib::PrimeGenerator::next ( )  [inline]
```

7.117.3 Member Data Documentation

7.117.3.1 k

```
long helib::PrimeGenerator::k
```

7.117.3.2 len

```
long helib::PrimeGenerator::len
```

7.117.3.3 m

```
long helib::PrimeGenerator::m
```

7.117.3.4 t

```
long helib::PrimeGenerator::t
```

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

- /HElib/src/primeChain.cpp

7.118 helib::print_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, std::ostream &s, const PlaintextArray &pa)

7.118.1 Member Function Documentation

7.118.1.1 apply()

```
template<typename type >
static void helib::print_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            std::ostream & s,
            const PlaintextArray & pa ) [inline], [static]
```

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

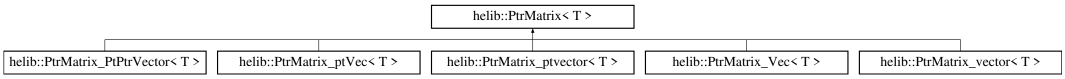
- /HElib/src/EncryptedArray.cpp

7.119 helib::PtrMatrix< T > Struct Template Reference

An abstract class for an array of PtrVectors.

```
#include <PtrMatrix.h>
```

Inheritance diagram for helib::PtrMatrix< T >:



Public Member Functions

- virtual PtrVector< T > & operator[ ] (long)=0
- virtual const PtrVector< T > & operator[ ] (long) const =0
- virtual long size () const =0
- virtual void resize (long newSize)
- virtual ∼PtrMatrix ()
- virtual const T ∗ ptr2nonNull () const

7.119.1 Detailed Description

template<typename T>
struct helib::PtrMatrix< T >

An abstract class for an array of PtrVectors.

7.119.2 Constructor & Destructor Documentation

7.119.2.1 ∼PtrMatrix()

```
template<typename T >
virtual helib::PtrMatrix< T >::∼PtrMatrix ( )  [inline], [virtual]
```

7.119.3 Member Function Documentation

7.119.3.1 operator[]() [1/2]

```
template<typename T >
virtual const PtrVector<T>& helib::PtrMatrix< T >::operator[] (
            long ) const [pure virtual]
```

Implemented in helib::PtrMatrix_PtPtrVector< T >, helib::PtrMatrix_ptvector< T >, helib::PtrMatrix_vector< T >, helib::PtrMatrix_ptVec< T >, and helib::PtrMatrix_Vec< T >.

7.119.3.2 operator[]() [2/2]

```
template<typename T >
virtual PtrVector<T>& helib::PtrMatrix< T >::operator[] (
            long ) [pure virtual]
```

Implemented in helib::PtrMatrix_PtPtrVector< T >, helib::PtrMatrix_ptvector< T >, helib::PtrMatrix_vector< T >, helib::PtrMatrix_ptVec< T >, and helib::PtrMatrix_Vec< T >.

7.119.3.3 ptr2nonNull()

```
template<typename T >
virtual const T* helib::PtrMatrix< T >::ptr2nonNull ( ) const [inline], [virtual]
```

7.119.3.4 resize()

```
template<typename T >
virtual void helib::PtrMatrix< T >::resize (
            long newSize ) [inline], [virtual]
```

Reimplemented in helib::PtrMatrix_vector< T >, and helib::PtrMatrix_Vec< T >.

7.119.3.5 size()

```
template<typename T >
virtual long helib::PtrMatrix< T >::size ( ) const [pure virtual]
```

Implemented in helib::PtrMatrix_PtPtrVector< T >, helib::PtrMatrix_ptvector< T >, helib::PtrMatrix_vector< T >, helib::PtrMatrix_ptVec< T >, and helib::PtrMatrix_Vec< T >.

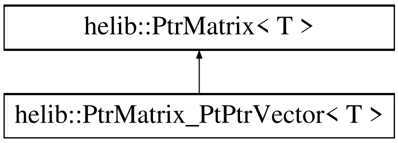
The documentation for this struct was generated from the following file:

- /HElib/include/helib/PtrMatrix.h

7.120 helib::PtrMatrix_PtPtrVector< T > Struct Template Reference

An implementation of PtrMatrix using vector< PtrVector<T>* >

Inheritance diagram for helib::PtrMatrix_PtPtrVector< T >:



Public Member Functions

- PtrMatrix_PtPtrVector (std::vector< PtrVector< T > * > &mat)
- PtrVector< T > & operator[ ] (long i) override
- const PtrVector< T > & operator[ ] (long i) const override
- long size () const override

Public Attributes

- std::vector< PtrVector< T > * > & rows

7.120.1 Detailed Description

template<typename T>
struct helib::PtrMatrix_PtPtrVector< T >

An implementation of PtrMatrix using vector< PtrVector<T>* >

7.120.2 Constructor & Destructor Documentation

7.120.2.1 PtrMatrix_PtPtrVector()

```
template<typename T >
helib::PtrMatrix_PtPtrVector< T >::PtrMatrix_PtPtrVector (
            std::vector< PtrVector< T > * > & mat )  [inline]
```

7.120.3 Member Function Documentation

7.120.3.1 operator[]() [1/2]

```
template<typename T >
const PtrVector<T>& helib::PtrMatrix_PtPtrVector< T >::operator[] (
            long i ) const [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.120.3.2 operator[]() [2/2]

```
template<typename T >
PtrVector<T>& helib::PtrMatrix_PtPtrVector< T >::operator[] (
            long i ) [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.120.3.3 size()

```
template<typename T >
long helib::PtrMatrix_PtPtrVector< T >::size ( ) const [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.120.4 Member Data Documentation

7.120.4.1 rows

```
template<typename T >
std::vector<PtrVector<T>*>& helib::PtrMatrix_PtPtrVector< T >::rows
```

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

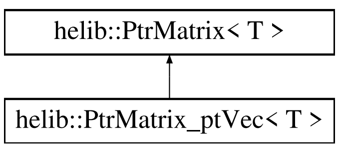
- /HElib/src/binaryArith.cpp

7.121 helib::PtrMatrix_ptVec< T > Struct Template Reference

An implementation of PtrMatrix using Vec< Vec<T>* >

```
#include <PtrMatrix.h>
```

Inheritance diagram for helib::PtrMatrix_ptVec< T >:



Public Member Functions

- PtrMatrix_ptVec (NTL::Vec< NTL::Vec< T > * > &mat)
- PtrVector< T > & operator[ ] (long i) override
- const PtrVector< T > & operator[ ] (long i) const override
- long size () const override

Public Attributes

- NTL::Vec< NTL::Vec< T > * > & buffer
- std::vector< PtrVector_VecT< T > > rows

7.121.1 Detailed Description

template<typename T>
struct helib::PtrMatrix_ptVec< T >

An implementation of PtrMatrix using Vec< Vec<T>* >

7.121.2 Constructor & Destructor Documentation

7.121.2.1 PtrMatrix_ptVec()

```
template<typename T >
helib::PtrMatrix_ptVec< T >::PtrMatrix_ptVec (
            NTL::Vec< NTL::Vec< T > * > & mat )  [inline]
```

7.121.3 Member Function Documentation

7.121.3.1 operator[]() [1/2]

```
template<typename T >
const PtrVector<T>& helib::PtrMatrix_ptVec< T >::operator[] (
            long i ) const  [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.121.3.2 operator[]() [2/2]

```
template<typename T >
PtrVector<T>& helib::PtrMatrix_ptVec< T >::operator[] (
              long i )  [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.121.3.3 size()

```
template<typename T >
long helib::PtrMatrix_ptVec< T >::size ( ) const  [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.121.4 Member Data Documentation

7.121.4.1 buffer

```
template<typename T >
NTL::Vec<NTL::Vec<T>*>& helib::PtrMatrix_ptVec< T >::buffer
```

7.121.4.2 rows

```
template<typename T >
std::vector<PtrVector_VecT<T> > helib::PtrMatrix_ptVec< T >::rows
```

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

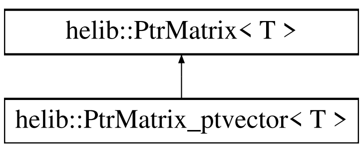
- /HElib/include/helib/PtrMatrix.h

7.122 helib::PtrMatrix_ptvector< T > Struct Template Reference

An implementation of PtrMatrix using vector< vector<T>∗ >

```
#include <PtrMatrix.h>
```

Inheritance diagram for helib::PtrMatrix_ptvector< T >:



Public Member Functions

- PtrMatrix_ptvector (std::vector< std::vector< T > * > &mat)
- PtrVector< T > & operator[ ] (long i) override
- const PtrVector< T > & operator[ ] (long i) const override
- long size () const override

Public Attributes

- std::vector< std::vector< T > * > & buffer
- std::vector< PtrVector_vectorT< T > > rows

7.122.1 Detailed Description

template<typename T>
struct helib::PtrMatrix_ptvector< T >

An implementation of PtrMatrix using vector< vector<T>* >

7.122.2 Constructor & Destructor Documentation

7.122.2.1 PtrMatrix_ptvector()

```
template<typename T >
helib::PtrMatrix_ptvector< T >::PtrMatrix_ptvector (
            std::vector< std::vector< T > * > & mat )  [inline]
```

7.122.3 Member Function Documentation

7.122.3.1 operator[]() [1/2]

```
template<typename T >
const PtrVector<T>& helib::PtrMatrix_ptvector< T >::operator[] (
            long i ) const  [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.122.3.2 operator[]() [2/2]

```
template<typename T >
PtrVector<T>& helib::PtrMatrix_ptvector< T >::operator[] (
            long i ) [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.122.3.3 size()

```
template<typename T >
long helib::PtrMatrix_ptvector< T >::size ( ) const [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.122.4 Member Data Documentation

7.122.4.1 buffer

```
template<typename T >
std::vector<std::vector<T>*>& helib::PtrMatrix_ptvector< T >::buffer
```

7.122.4.2 rows

```
template<typename T >
std::vector<PtrVector_vectorT<T> > helib::PtrMatrix_ptvector< T >::rows
```

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

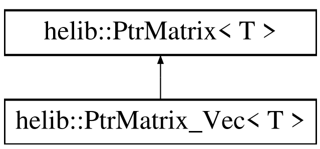
- /HElib/include/helib/PtrMatrix.h

7.123 helib::PtrMatrix_Vec< T > Struct Template Reference

An implementation of PtrMatrix using Vec< Vec<T> >

```
#include <PtrMatrix.h>
```

Inheritance diagram for helib::PtrMatrix_Vec< T >:



Public Member Functions

- PtrMatrix_Vec (NTL::Vec< NTL::Vec< T >> &mat)
- PtrVector< T > & operator[] (long i) override
- const PtrVector< T > & operator[] (long i) const override
- long size () const override
- void resize (long newSize) override

Public Attributes

- NTL::Vec< NTL::Vec< T > > & buffer
- std::vector< PtrVector_VecT< T > > rows

7.123.1 Detailed Description

template<typename T>
struct helib::PtrMatrix_Vec< T >

An implementation of PtrMatrix using Vec< Vec<T> >

7.123.2 Constructor & Destructor Documentation

7.123.2.1 PtrMatrix_Vec()

```
template<typename T >
helib::PtrMatrix_Vec< T >::PtrMatrix_Vec (
            NTL::Vec< NTL::Vec< T >> & mat )  [inline]
```

7.123.3 Member Function Documentation

7.123.3.1 operator[]() [1/2]

```
template<typename T >
const PtrVector<T>& helib::PtrMatrix_Vec< T >::operator[] (
            long i ) const  [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.123.3.2 operator[]() [2/2]

```
template<typename T >
PtrVector<T>& helib::PtrMatrix_Vec< T >::operator[] (
            long i ) [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.123.3.3 resize()

```
template<typename T >
void helib::PtrMatrix_Vec< T >::resize (
            long newSize ) [inline], [override], [virtual]
```

Reimplemented from helib::PtrMatrix< T >.

7.123.3.4 size()

```
template<typename T >
long helib::PtrMatrix_Vec< T >::size ( ) const [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.123.4 Member Data Documentation

7.123.4.1 buffer

```
template<typename T >
NTL::Vec<NTL::Vec<T> >& helib::PtrMatrix_Vec< T >::buffer
```

7.123.4.2 rows

```
template<typename T >
std::vector<PtrVector_VecT<T> > helib::PtrMatrix_Vec< T >::rows
```

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

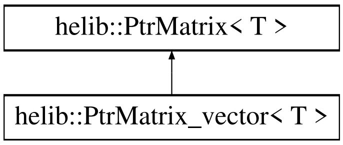
- /HElib/include/helib/PtrMatrix.h

7.124 helib::PtrMatrix_vector< T > Struct Template Reference

An implementation of PtrMatrix using vector< vector<T> >

```
#include <PtrMatrix.h>
```

Inheritance diagram for helib::PtrMatrix_vector< T >:



Public Member Functions

- PtrMatrix_vector (std::vector< std::vector< T >> &mat)
- PtrVector< T > & operator[ ] (long i) override
- const PtrVector< T > & operator[ ] (long i) const override
- long size () const override
- void resize (long newSize) override

Public Attributes

- std::vector< std::vector< T > > & buffer
- std::vector< PtrVector_vectorT< T > > rows

7.124.1 Detailed Description

template<typename T>
struct helib::PtrMatrix_vector< T >

An implementation of PtrMatrix using vector< vector<T> >

7.124.2 Constructor & Destructor Documentation

7.124.2.1 PtrMatrix_vector()

```
template<typename T >
helib::PtrMatrix_vector< T >::PtrMatrix_vector (
            std::vector< std::vector< T >> & mat )  [inline]
```

7.124.3 Member Function Documentation

7.124.3.1 operator[]() [1/2]

```
template<typename T >
const PtrVector<T>& helib::PtrMatrix_vector< T >::operator[] (
            long i ) const  [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.124.3.2 operator[]() [2/2]

```
template<typename T >
PtrVector<T>& helib::PtrMatrix_vector< T >::operator[] (
            long i )  [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.124.3.3 resize()

```
template<typename T >
void helib::PtrMatrix_vector< T >::resize (
            long newSize )  [inline], [override], [virtual]
```

Reimplemented from helib::PtrMatrix< T >.

7.124.3.4 size()

```
template<typename T >
long helib::PtrMatrix_vector< T >::size ( ) const  [inline], [override], [virtual]
```

Implements helib::PtrMatrix< T >.

7.124.4 Member Data Documentation

7.124.4.1 buffer

```
template<typename T >
std::vector<std::vector<T> >& helib::PtrMatrix_vector< T >::buffer
```

7.124.4.2 rows

```
template<typename T >
std::vector<PtrVector_vectorT<T> > helib::PtrMatrix_vector< T >::rows
```

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

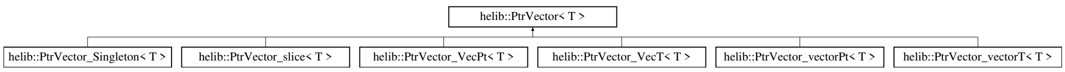
- /HElib/include/helib/PtrMatrix.h

7.125 helib::PtrVector< T > Struct Template Reference

Abstract class for an array of objects.

```
#include <PtrVector.h>
```

Inheritance diagram for helib::PtrVector< T >:



Public Member Functions

- virtual T ∗ operator[ ] (long) const =0
- virtual long size () const =0
- virtual void resize (long newSize, UNUSED const PtrVector ∗another=nullptr)
- virtual ∼PtrVector ()
- bool isSet (long i) const
- virtual long numNonNull (long first=0, long last=LONG_MAX) const
- virtual const T ∗ ptr2nonNull () const

7.125.1 Detailed Description

template<typename T>
struct helib::PtrVector< T >

Abstract class for an array of objects.

7.125.2 Constructor & Destructor Documentation

7.125.2.1 ∼PtrVector()

```
template<typename T >
virtual helib::PtrVector< T >::~PtrVector ( ) [inline], [virtual]
```

7.125.3 Member Function Documentation

7.125.3.1 isSet()

```
template<typename T >
bool helib::PtrVector< T >::isSet (
            long i ) const  [inline]
```

7.125.3.2 numNonNull()

```
template<typename T >
virtual long helib::PtrVector< T >::numNonNull (
            long first = 0,
            long last = LONG_MAX ) const  [inline], [virtual]
```

Reimplemented in helib::PtrVector_slice< T >, helib::PtrVector_vectorT< T >, and helib::PtrVector_VecT< T >.

7.125.3.3 operator[]()

```
template<typename T >
virtual T* helib::PtrVector< T >::operator[] (
            long ) const  [pure virtual]
```

Implemented in helib::PtrVector_Singleton< T >, helib::PtrVector_slice< T >, helib::PtrVector_vectorT< T >, helib::PtrVector_VecT< T >, helib::PtrVector_vectorPt< T >, and helib::PtrVector_VecPt< T >.

7.125.3.4 ptr2nonNull()

```
template<typename T >
virtual const T* helib::PtrVector< T >::ptr2nonNull ( ) const  [inline], [virtual]
```

Reimplemented in helib::PtrVector_slice< T >, and helib::PtrVector_VecT< T >.

7.125.3.5 resize()

```
template<typename T >
virtual void helib::PtrVector< T >::resize (
            long newSize,
            UNUSED const PtrVector< T > * another = nullptr )  [inline], [virtual]
```

Reimplemented in helib::PtrVector_vectorPt< T >, and helib::PtrVector_VecPt< T >.

7.125.3.6 size()

```
template<typename T >
virtual long helib::PtrVector< T >::size ( ) const  [pure virtual]
```

Implemented in helib::PtrVector_Singleton< T >, helib::PtrVector_slice< T >, helib::PtrVector_vectorT< T >, helib::PtrVector_VecT< T >, helib::PtrVector_vectorPt< T >, and helib::PtrVector_VecPt< T >.

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

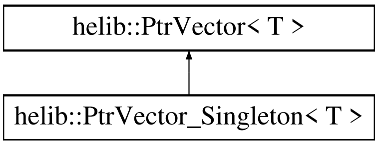
- /HElib/include/helib/PtrVector.h

7.126 helib::PtrVector_Singleton< T > Struct Template Reference

An implementation of PtrVector from a single T object.

```
#include <PtrVector.h>
```

Inheritance diagram for helib::PtrVector_Singleton< T >:



Public Member Functions

- PtrVector_Singleton (const T ∗_v)
- T ∗ operator[ ] (long i) const override
- long size () const override

Public Attributes

- const T ∗ v

7.126.1 Detailed Description

template<typename T>
struct helib::PtrVector_Singleton< T >

An implementation of PtrVector from a single T object.

7.126.2 Constructor & Destructor Documentation

7.126.2.1 PtrVector_Singleton()

```
template<typename T >
helib::PtrVector_Singleton< T >::PtrVector_Singleton (
            const T * _v )  [inline]
```

7.126.3 Member Function Documentation

7.126.3.1 operator[]()

```
template<typename T >
T* helib::PtrVector_Singleton< T >::operator[] (
            long i ) const  [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.126.3.2 size()

```
template<typename T >
long helib::PtrVector_Singleton< T >::size ( ) const  [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.126.4 Member Data Documentation

7.126.4.1 v

```
template<typename T >
const T* helib::PtrVector_Singleton< T >::v
```

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

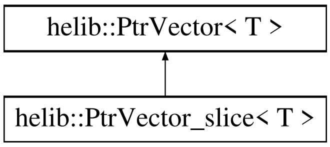
- /HElib/include/helib/PtrVector.h

7.127 helib::PtrVector_slice< T > Struct Template Reference

An implementation of PtrVector as a slice of another PtrVector.

```
#include <PtrVector.h>
```

Inheritance diagram for helib::PtrVector_slice< T >:



Public Member Functions

- PtrVector_slice (const PtrVector_slice< T > &slice, long from, long _sz=-1)
- PtrVector_slice (const PtrVector< T > &_orig, long from, long _sz=-1)
- T $*$ operator[ ] (long i) const override
- long size () const override
- long numNonNull (long first=0, long last=LONG_MAX) const override
- const T $*$ ptr2nonNull () const override

Public Attributes

- const PtrVector< T > & orig
- long start
- long sz

7.127.1 Detailed Description

template<typename T>
struct helib::PtrVector_slice< T >

An implementation of PtrVector as a slice of another PtrVector.

7.127.2 Constructor & Destructor Documentation

7.127.2.1 PtrVector_slice() [1/2]

```
template<typename T >
helib::PtrVector_slice< T >::PtrVector_slice (
            const PtrVector_slice< T > & slice,
            long from,
            long _sz = -1 )  [inline]
```

7.127.2.2 PtrVector_slice() [2/2]

```
template<typename T >
helib::PtrVector_slice< T >::PtrVector_slice (
            const PtrVector< T > & _orig,
            long from,
            long _sz = -1 )  [inline]
```

7.127.3 Member Function Documentation

7.127.3.1 numNonNull()

```
template<typename T >
long helib::PtrVector_slice< T >::numNonNull (
            long first = 0,
            long last = LONG_MAX ) const  [inline], [override], [virtual]
```

Reimplemented from helib::PtrVector< T >.

7.127.3.2 operator[]()

```
template<typename T >
T* helib::PtrVector_slice< T >::operator[] (
            long i ) const  [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.127.3.3 ptr2nonNull()

```
template<typename T >
const T* helib::PtrVector_slice< T >::ptr2nonNull ( ) const  [inline], [override], [virtual]
```

Reimplemented from helib::PtrVector< T >.

7.127.3.4 size()

```
template<typename T >
long helib::PtrVector_slice< T >::size ( ) const  [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.127.4 Member Data Documentation

7.127.4.1 orig

```
template<typename T >
const PtrVector<T>& helib::PtrVector_slice< T >::orig
```

7.127.4.2 start

```
template<typename T >
long helib::PtrVector_slice< T >::start
```

7.127.4.3 sz

```
template<typename T >
long helib::PtrVector_slice< T >::sz
```

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

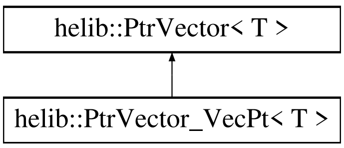
- /HElib/include/helib/PtrVector.h

7.128 helib::PtrVector_VecPt< T > Struct Template Reference

An implementation of PtrVector using Vec<T*>

```
#include <PtrVector.h>
```

Inheritance diagram for helib::PtrVector_VecPt< T >:



Public Member Functions

- PtrVector_VecPt (NTL::Vec< T * > &_v)
- T * operator[ ] (long i) const override
- long size () const override
- void resize (long newSize, UNUSED const PtrVector< T > *another=nullptr) override

Public Attributes

- NTL::Vec< T * > & v

7.128.1 Detailed Description

template<typename T>
struct helib::PtrVector_VecPt< T >

An implementation of PtrVector using Vec<T*>

7.128.2 Constructor & Destructor Documentation

7.128.2.1 PtrVector_VecPt()

```
template<typename T >
helib::PtrVector_VecPt< T >::PtrVector_VecPt (
            NTL::Vec< T * > & _v )  [inline]
```

7.128.3 Member Function Documentation

7.128.3.1 operator[]()

```
template<typename T >
T* helib::PtrVector_VecPt< T >::operator[] (
            long i ) const  [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.128.3.2 resize()

```
template<typename T >
void helib::PtrVector_VecPt< T >::resize (
            long newSize,
            UNUSED const PtrVector< T > * another = nullptr )  [inline], [override], [virtual]
```

Reimplemented from helib::PtrVector< T >.

7.128.3.3 size()

```
template<typename T >
long helib::PtrVector_VecPt< T >::size ( ) const  [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.128.4 Member Data Documentation

7.128.4.1 v

```
template<typename T >
NTL::Vec<T*>& helib::PtrVector_VecPt< T >::v
```

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

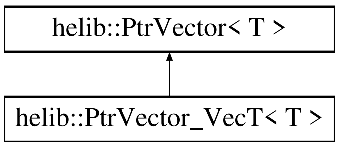
- /HElib/include/helib/PtrVector.h

7.129 helib::PtrVector_VecT< T > Struct Template Reference

An implementation of PtrVector using Vec<T>

```
#include <PtrVector.h>
```

Inheritance diagram for helib::PtrVector_VecT< T >:



Public Member Functions

- PtrVector_VecT (NTL::Vec< T > &_v)
- T * operator[] (long i) const override
- long size () const override
- void resize (long newSize, const PtrVector< T > *another) override
- long numNonNull (long first=0, long last=LONG_MAX) const override
- const T * ptr2nonNull () const override

Public Attributes

- NTL::Vec< T > & v

7.129.1 Detailed Description

template<typename T>
struct helib::PtrVector_VecT< T >

An implementation of PtrVector using Vec<T>

7.129.2 Constructor & Destructor Documentation

7.129.2.1 PtrVector_VecT()

```
template<typename T >
helib::PtrVector_VecT< T >::PtrVector_VecT (
            NTL::Vec< T > & _v )  [inline]
```

7.129.3 Member Function Documentation

7.129.3.1 numNonNull()

```
template<typename T >
long helib::PtrVector_VecT< T >::numNonNull (
            long first = 0,
            long last = LONG_MAX ) const  [inline], [override], [virtual]
```

Reimplemented from helib::PtrVector< T >.

7.129.3.2 operator[]()

```
template<typename T >
T* helib::PtrVector_VecT< T >::operator[] (
            long i ) const  [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.129.3.3 ptr2nonNull()

```
template<typename T >
const T* helib::PtrVector_VecT< T >::ptr2nonNull ( ) const  [inline], [override], [virtual]
```

Reimplemented from helib::PtrVector< T >.

7.129.3.4 resize()

```
template<typename T >
void helib::PtrVector_VecT< T >::resize (
            long newSize,
            const PtrVector< T > * another )  [inline], [override]
```

7.129.3.5 size()

```
template<typename T >
long helib::PtrVector_VecT< T >::size ( ) const  [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.129.4 Member Data Documentation

7.129.4.1 v

```
template<typename T >
NTL::Vec<T>& helib::PtrVector_VecT< T >::v
```

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

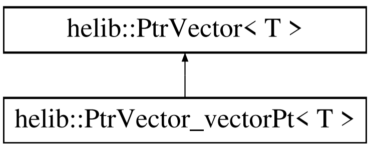
- /HElib/include/helib/PtrVector.h

7.130 helib::PtrVector_vectorPt< T > Struct Template Reference

An implementation of PtrVector using vector<T∗>

```
#include <PtrVector.h>
```

Inheritance diagram for helib::PtrVector_vectorPt< T >:



Public Member Functions

- PtrVector_vectorPt (std::vector< T ∗ > &_v)
- T ∗ operator[ ] (long i) const override
- long size () const override
- void resize (long newSize, UNUSED const PtrVector< T > ∗another=nullptr) override

Public Attributes

- std::vector< T * > & v

7.130.1 Detailed Description

template<typename T>
struct helib::PtrVector_vectorPt< T >

An implementation of PtrVector using vector<T*>

7.130.2 Constructor & Destructor Documentation

7.130.2.1 PtrVector_vectorPt()

```
template<typename T >
helib::PtrVector_vectorPt< T >::PtrVector_vectorPt (
            std::vector< T * > & _v )  [inline]
```

7.130.3 Member Function Documentation

7.130.3.1 operator[]()

```
template<typename T >
T* helib::PtrVector_vectorPt< T >::operator[] (
            long i ) const  [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.130.3.2 resize()

```
template<typename T >
void helib::PtrVector_vectorPt< T >::resize (
            long newSize,
            UNUSED const PtrVector< T > * another = nullptr )  [inline], [override], [virtual]
```

Reimplemented from helib::PtrVector< T >.

7.130.3.3 size()

```
template<typename T >
long helib::PtrVector_vectorPt< T >::size ( ) const [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.130.4 Member Data Documentation

7.130.4.1 v

```
template<typename T >
std::vector<T*>& helib::PtrVector_vectorPt< T >::v
```

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

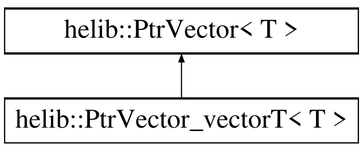
- /HElib/include/helib/PtrVector.h

7.131 helib::PtrVector_vectorT< T > Struct Template Reference

An implementation of PtrVector using vector<T>

```
#include <PtrVector.h>
```

Inheritance diagram for helib::PtrVector_vectorT< T >:



Public Member Functions

- PtrVector_vectorT (std::vector< T > &_v)
- T ∗ operator[ ] (long i) const override
- long size () const override
- void resize (long newSize, const PtrVector< T > ∗another) override
- long numNonNull (long first=0, long last=LONG_MAX) const override

Public Attributes

- std::vector< T > & v

7.131.1 Detailed Description

template<typename T>
struct helib::PtrVector_vectorT< T >

An implementation of PtrVector using vector<T>

7.131.2 Constructor & Destructor Documentation

7.131.2.1 PtrVector_vectorT()

```
template<typename T >
helib::PtrVector_vectorT< T >::PtrVector_vectorT (
            std::vector< T > & _v )  [inline]
```

7.131.3 Member Function Documentation

7.131.3.1 numNonNull()

```
template<typename T >
long helib::PtrVector_vectorT< T >::numNonNull (
            long first = 0,
            long last = LONG_MAX ) const  [inline], [override], [virtual]
```

Reimplemented from helib::PtrVector< T >.

7.131.3.2 operator[]()

```
template<typename T >
T* helib::PtrVector_vectorT< T >::operator[] (
            long i ) const  [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.131.3.3 resize()

```
template<typename T >
void helib::PtrVector_vectorT< T >::resize (
            long newSize,
            const PtrVector< T > * another )  [inline], [override]
```

7.131.3.4 size()

```
template<typename T >
long helib::PtrVector_vectorT< T >::size ( ) const [inline], [override], [virtual]
```

Implements helib::PtrVector< T >.

7.131.4 Member Data Documentation

7.131.4.1 v

```
template<typename T >
std::vector<T>& helib::PtrVector_vectorT< T >::v
```

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

- /HElib/include/helib/PtrVector.h

7.132 helib::Ptxt Class Reference

An object that mimics the functionality of the `Ctxt` object, and acts as a convenient entry point for inputting/encoding data which is to be encrypted.

`#include <Ctxt.h>`

Public Types

- using SlotType = typename Scheme::SlotType
  Alias for type to be stored in the slots.

Public Member Functions

- Ptxt ()
  Default constructor results in invalid `Ptxt` object which throws if used.
- Ptxt (const Context &context)
  Context only constructor, defaults all slots to `0`.
- Ptxt (const Context &context, const SlotType &value)
  Single slot constructor, set all slots to `value`.
- template<typename U = Scheme, std::enable_if_t< std::is_same< U, BGV >::value > * = nullptr>
  Ptxt (const Context &context, const NTL::ZZX &value)
  BGV plaintext polynomial constructor, set all slots to the `value` polynomial.
- Ptxt (const Context &context, const std::vector< SlotType > &data)
  Slot vector constructor.

- template<typename T >
  Ptxt (const Context &context, const std::vector< T > &data)

  Generic slot vector constructor.
- Ptxt (const Ptxt< Scheme > &other)=default

  Default copy constructor.
- Ptxt (Ptxt< Scheme > &&other) noexcept=default

  Default move constructor.
- Ptxt< Scheme > & operator= (const Ptxt< Scheme > &v)=default

  Copy assignment operator with other `Ptxt`.
- Ptxt< Scheme > & operator= (Ptxt< Scheme > &&v) noexcept=default

  Move assignment operator with other `Ptxt`.
- ∼Ptxt ()=default

  Default destructor.
- bool isValid () const

  Check if a `Ptxt` is valid.
- size_t size () const

  Returns the size (number of slots) of a `Ptxt`.
- long lsize () const

  Returns the size (number of slots) of a `Ptxt` as `long`.
- void setData (const std::vector< SlotType > &data)

  Set the data.
- void setData (const SlotType &value)

  Set the data replicating the input on all slots.
- template<typename T = Scheme, typename std::enable_if_t< std::is_same< T, BGV >::value > ∗ = nullptr>
  void setData (const NTL::ZZX &value)

  Set the `Ptxt` data replicating the input polynomial on all slots.
- template<typename T = Scheme, typename std::enable_if_t< std::is_same< T, BGV >::value > ∗ = nullptr>
  void decodeSetData (const NTL::ZZX &data)

  Set the `Ptxt` slots using values from decoding `data` to slot representation.
- void clear ()

  Sets all slots to `0`.
- Ptxt< Scheme > & random ()

  Populate slots with random data.
- const std::vector< SlotType > & getSlotRepr () const

  Get the data held in the slots as a `std::vector<SlotType>`.
- NTL::ZZX getPolyRepr () const

  Converts the slot data in `this` to its single polynomial representation.
- SlotType & operator[ ] (long i)

  Square bracket accessor operator.
- SlotType operator[ ] (long i) const

  `const` square bracket accessor operator.
- SlotType & at (long i)

  `at` accessor operator.
- SlotType at (long i) const

  `const at` accessor operator.
- bool operator== (const Ptxt< Scheme > &other) const

  Equals operator between two `Ptxt` objects.
- bool operator!= (const Ptxt< Scheme > &other) const

  Not equals operator between two `Ptxt` objects.
- Ptxt< Scheme > operator∗ (const Ptxt< Scheme > &rhs) const

  Infix multiplication operator.

- Ptxt< Scheme > operator+ (const Ptxt< Scheme > &rhs) const

  Infix addition operator.
- Ptxt< Scheme > operator- (const Ptxt< Scheme > &rhs) const

  Infix subtraction operator.
- Ptxt< Scheme > & operator*= (const Ptxt< Scheme > &otherPtxt)

  Times equals operator with another `Ptxt`.
- Ptxt< Scheme > & operator*= (const SlotType &scalar)

  Times equals operator with a single `SlotType`.
- template<typename Scalar >
  Ptxt< Scheme > & operator*= (const Scalar &scalar)

  Times equals operator with a scalar.
- Ptxt< Scheme > & operator+= (const Ptxt< Scheme > &otherPtxt)

  Plus equals operator with another `Ptxt`.
- Ptxt< Scheme > & operator+= (const SlotType &scalar)

  Plus equals operator with a single `SlotType`.
- template<typename Scalar >
  Ptxt< Scheme > & operator+= (const Scalar &scalar)

  Plus equals operator with a scalar.
- Ptxt< Scheme > & operator-= (const Ptxt< Scheme > &otherPtxt)

  Minus equals operator with another `Ptxt`.
- Ptxt< Scheme > & operator-= (const SlotType &scalar)

  Minus equals operator with a single `SlotType`.
- template<typename Scalar >
  Ptxt< Scheme > & operator-= (const Scalar &scalar)

  Minus equals operator with a scalar.
- Ptxt< Scheme > & negate ()

  Negate a `Ptxt`.
- template<typename T = Scheme, typename Scalar , typename std::enable_if_t< std::is_same< T, BGV >::value > * = nullptr>
  Ptxt< Scheme > & addConstant (const Scalar &scalar)

  Add a constant to a BGV `Ptxt`.
- template<typename T = Scheme, typename Scalar , typename std::enable_if_t< std::is_same< T, CKKS >::value > * = nullptr>
  Ptxt< Scheme > & addConstantCKKS (const Scalar &scalar)

  Add a constant to a CKKS `Ptxt`.
- Ptxt< Scheme > & multiplyBy (const Ptxt< Scheme > &otherPtxt)

  Multiplication function between two `Ptxt` objects.
- Ptxt< Scheme > & multiplyBy2 (const Ptxt &otherPtxt1, const Ptxt &otherPtxt2)

  Multiplication function between three `Ptxt` objects.
- Ptxt< Scheme > & square ()

  Square operation on a `Ptxt`.
- Ptxt< Scheme > & cube ()

  Cube operation on a `Ptxt`.
- Ptxt< Scheme > & power (long e)

  Power operation to raise a `Ptxt` to an arbitrary non-negative power.
- Ptxt< Scheme > & rotate (long amount)

  Rotate slots right by specified amount (slot `i` goes to slot `i+1 mod size`).
- Ptxt< Scheme > & rotate1D (long dim, long amount)

  Rotate slots right by specified amount along a specific dimension.
- Ptxt< Scheme > & shift (long amount)

  Shifts slots right by specified amount with `0` fill (slot `i` goes to slot `i+1 mod size`).
- Ptxt< Scheme > & shift1D (long dim, long amount)

  Shift slots right in one dimension of the hypercube structure with `0` fill.

- Ptxt< Scheme > & automorph (long k)

  Apply the automorphism a(X) -> a(X^k) mod Phi_m(X).
- template<typename T = Scheme, std::enable_if_t< std::is_same< T, BGV >::value > ∗ = nullptr>
  Ptxt< Scheme > & frobeniusAutomorph (long j)

  Apply the frobenius automorphism a(X) -> a(X^(p^j)) mod Phi_m(X).
- Ptxt< Scheme > & replicate (long pos)

  Replicate single slot across all slots.
- std::vector< Ptxt< Scheme > > replicateAll () const

  Generate a vector of plaintexts with each slot replicated in each plaintext.
- template<typename T = Scheme, std::enable_if_t< std::is_same< T, CKKS >::value > ∗ = nullptr>
  Ptxt< Scheme > & complexConj ()

  Apply complex conjugate of complex numbers in slots of a `CKKS` `Ptxt` object.
- template<typename T = Scheme, std::enable_if_t< std::is_same< T, CKKS >::value > ∗ = nullptr>
  Ptxt< Scheme > real () const

  Extract the real part of a CKKS plaintext.
- template<typename T = Scheme, std::enable_if_t< std::is_same< T, CKKS >::value > ∗ = nullptr>
  Ptxt< Scheme > imag () const

  Extract the imaginary part of a CKKS plaintext.
- Ptxt< Scheme > & runningSums ()

  Compute the running sum (each slot is the sum of the previous slots).
- Ptxt< Scheme > & totalSums ()

  Compute the total sum (each slot contains the total sum of every slot).
- Ptxt< Scheme > & incrementalProduct ()

  Compute the incremental product (each slot is the product of the previous slots).
- Ptxt< Scheme > & totalProduct ()

  Compute the total product (each slot contains the total product of every slot).
- Ptxt< Scheme > & mapTo01 ()

  Map all non-zero slots to `1`, keeping zero slots as zero.
- PolyMod convertToSlot (const Context &context, long slot)
- std::complex< double > convertToSlot (const Context &, long slot)
- template<typename Scheme >
  Ptxt ()
- template<typename Scheme >
  Ptxt (const Context &context)
- template<typename Scheme >
  Ptxt (const Context &context, const SlotType &value)
- void setData (const NTL::ZZX &value)
- Ptxt (const Context &context, const NTL::ZZX &value)
- template<typename Scheme >
  Ptxt (const Context &context, const std::vector< SlotType > &data)
- template<typename Scheme >
  void setData (const std::vector< SlotType > &data)
- template<typename Scheme >
  void setData (const SlotType &value)
- void decodeSetData (const NTL::ZZX &data)
- NTL::ZZX getPolyRepr () const

  BGV specialisation of the `getPolyRepr` function.
- NTL::ZZX getPolyRepr () const

  CKKS specialisation of the `getPolyRepr` function.
- template<typename Scheme >
  Ptxt< Scheme > & operator∗= (const Ptxt< Scheme > &otherPtxt)
- template<typename Scheme >
  Ptxt< Scheme > & operator∗= (const SlotType &scalar)

- template<typename Scheme >
  Ptxt< Scheme > & operator+= (const Ptxt< Scheme > &otherPtxt)
- template<typename Scheme >
  Ptxt< Scheme > & operator+= (const SlotType &scalar)
- template<typename Scheme >
  Ptxt< Scheme > & operator-= (const Ptxt< Scheme > &otherPtxt)
- template<typename Scheme >
  Ptxt< Scheme > & operator-= (const SlotType &scalar)
- Ptxt< BGV > & automorph (long k)
- Ptxt< CKKS > & automorph (long k)
- Ptxt< BGV > & frobeniusAutomorph (long j)
- Ptxt< CKKS > & complexConj ()
- Ptxt< CKKS > real () const
- Ptxt< CKKS > imag () const

Static Public Member Functions

- static SlotType convertToSlot (const Context &context, long slot)

  Conversion function from `long` to `SlotType`.

Friends

- std::istream & operator>> (std::istream &is, Ptxt< Scheme > &ptxt)

  Input shift operator.
- std::ostream & operator<< (std::ostream &os, const Ptxt< Scheme > &ptxt)

  Output shift operator.

7.132.1 Detailed Description

An object that mimics the functionality of the `Ctxt` object, and acts as a convenient entry point for inputting/encoding data which is to be encrypted.

`Ptxt` is templated on `Scheme`, which may be `CKKS` or `BGV`.

In the BGV case, `Ptxt` can be considered to be an element of $\mathbb{Z}_p[x]/\Phi(m)$ viewed as a vector of slots with values each in $\mathbb{Z}_p[x]/G$ where G is one of the irreducible factors of $\Phi(m)$, and all operations are performed entry-wise.

General usage:
```
helib::Ptxt<BGV> p1(bgv_context, data);
helib::Ptxt<BGV> p2(bgv_context, data);
p1 += p2;
std::cout « p1 « std::endl;
```

Internally, `Ptxt` objects store their data as a `std::vector<helib::PolyMod>`, where `PolyMod` is a convenience type representing an element of the above ring, $\mathbb{Z}_p[x]/G$. The `PolyMod` type can be easily converted via `static_cast` to more convenient types such as `long` and `NTL::ZZX`.

In the `CKKS` case, the slot type is `std::complex<double>`, and has sensible operator overloads supporting operations with other `Ptxt<CKKS>`, `Ctxt`, and `std::complex<double>` objects, as well as performing all operations slot-wise.

A large number of operator overloads are defined so that `Ptxt` objects should easily inter-operate, as well as providing interoperability with other logically compatible types e.g. `long` and `NTL::ZZX` in the BGV case, `std↵ ::complex<double>` in the `CKKS` case, and `helib::Ctxt` in both cases.

7.132.2 Member Typedef Documentation

7.132.2.1 SlotType

```
using helib::Ptxt::SlotType = typename Scheme::SlotType
```

Alias for type to be stored in the slots.

`std::complex<double>` for CKKS, `helib::PolyMod` for BGV.

7.132.3 Constructor & Destructor Documentation

7.132.3.1 Ptxt() [1/13]

```
helib::Ptxt::Ptxt ( )
```

Default constructor results in invalid `Ptxt` object which throws if used.

7.132.3.2 Ptxt() [2/13]

```
helib::Ptxt::Ptxt (
            const Context & context )  [explicit]
```

Context only constructor, defaults all slots to `0`.

Parameters

context	`Context` to use.

7.132.3.3 Ptxt() [3/13]

```
helib::Ptxt::Ptxt (
            const Context & context,
            const SlotType & value )
```

Single slot constructor, set all slots to `value`.

Parameters

context	Context to use.
value	Value to set all slots to.

7.132.3.4 Ptxt() [4/13]

```
template<typename U = Scheme, std::enable_if_t< std::is_same< U, BGV >::value > * = nullptr>
helib::Ptxt::Ptxt (
            const Context & context,
            const NTL::ZZX & value )
```

BGV plaintext polynomial constructor, set all slots to the `value` polynomial.

Parameters

context	Context to use.
data	Polynomial to be converted into slot representation.

Note

Only exists for BGV.

7.132.3.5 Ptxt() [5/13]

```
helib::Ptxt::Ptxt (
            const Context & context,
            const std::vector< SlotType > & data )
```

Slot vector constructor.

Parameters

context	Context to use.

Parameters

data	Data to populate the slots.

7.132.3.6 Ptxt() [6/13]

```
template<typename T >
helib::Ptxt::Ptxt (
            const Context & context,
            const std::vector< T > & data ) [inline]
```

Generic slot vector constructor.

Parameters

context	Context to use.
data	Data to populate the slots, must be convertible to SlotType.

7.132.3.7 Ptxt() [7/13]

```
helib::Ptxt::Ptxt (
            const Ptxt< Scheme > & other ) [default]
```

Default copy constructor.

Parameters

other	Ptxt object to copy.

7.132.3.8 Ptxt() [8/13]

```
helib::Ptxt::Ptxt (
            Ptxt< Scheme > && other )  [default], [noexcept]
```

Default move constructor.

Parameters

other	Ptxt to copy.

7.132.3.9 ∼Ptxt()

```
helib::Ptxt::∼Ptxt ( )  [default]
```

Default destructor.

7.132.3.10 Ptxt() [9/13]

```
template<typename Scheme >
helib::Ptxt::Ptxt ( )
```

7.132.3.11 Ptxt() [10/13]

```
template<typename Scheme >
helib::Ptxt::Ptxt (
            const Context & context )
```

7.132.3.12 Ptxt() [11/13]

```
template<typename Scheme >
helib::Ptxt::Ptxt (
            const Context & context,
            const SlotType & value )
```

7.132.3.13 Ptxt() [12/13]

```
helib::Ptxt< BGV >::Ptxt (
            const Context & context,
            const NTL::ZZX & value )
```

7.132.3.14 Ptxt() [13/13]

```
template<typename Scheme >
helib::Ptxt::Ptxt (
            const Context & context,
            const std::vector< SlotType > & data )
```

7.132.4 Member Function Documentation

7.132.4.1 addConstant()

```
template<typename T = Scheme, typename Scalar , typename std::enable_if_t< std::is_same< T,
BGV >::value > * = nullptr>
Ptxt<Scheme>& helib::Ptxt::addConstant (
            const Scalar & scalar )  [inline]
```

Add a constant to a BGV `Ptxt`.

Parameters

scalar	Element to be added across all slots.

Returns

Reference to `*this` post scalar addition.

7.132.4.2 addConstantCKKS()

```
template<typename T = Scheme, typename Scalar , typename std::enable_if_t< std::is_same< T,
CKKS >::value > * = nullptr>
Ptxt<Scheme>& helib::Ptxt::addConstantCKKS (
            const Scalar & scalar )  [inline]
```

Add a constant to a CKKS `Ptxt`.

Parameters

scalar	Element to be added across all slots.

Returns

Reference to `*this` post scalar addition.

7.132.4.3 at() [1/2]

```
Ptxt< Scheme >::SlotType & helib::Ptxt::at (
            long i )
```

`at` accessor operator.

Parameters

i	Index of the desired `Ptxt` slot.

Returns

Reference to the data held at slot `i`.

Note

throws if `i` is out of range.

7.132.4.4 at() [2/2]

```
Ptxt< Scheme >::SlotType helib::Ptxt::at (
            long i ) const
```

`const at` accessor operator.

Parameters

i	Index of the desired Ptxt slot.

Returns

Copy of the data held at slot `i`.

Note

throws if `i` is out of range.

7.132.4.5 automorph() [1/3]

```
Ptxt<Scheme>& helib::Ptxt::automorph (
            long k )
```

Apply the automorphism a(X) -> a(X^k) mod Phi_m(X).

Parameters

k	Exponent of the automorphism to apply.

Returns

Reference to `*this` post automorphism application.

Note

`k` must be an element of Zm*

7.132.4.6 automorph() [2/3]

```
Ptxt< BGV > & helib::Ptxt< BGV >::automorph (
            long k )
```

7.132.4.7 automorph() [3/3]

```
Ptxt< CKKS > & helib::Ptxt< CKKS >::automorph (
            long k )
```

7.132.4.8 clear()

```
void helib::Ptxt::clear ( )
```

Sets all slots to `0`.

7.132.4.9 complexConj() [1/2]

```
template<typename T = Scheme, std::enable_if_t< std::is_same< T, CKKS >::value > * = nullptr>
Ptxt<Scheme>& helib::Ptxt::complexConj ( )
```

Apply complex conjugate of complex numbers in slots of a `CKKS` `Ptxt` object.

Returns

Reference to `*this` post complex conjugation.

Note

Only valid for the `CKKS` scheme.

7.132.4.10 complexConj() [2/2]

```
Ptxt< CKKS > & helib::Ptxt< CKKS >::complexConj ( )
```

7.132.4.11 convertToSlot() [1/3]

```
std::complex< double > helib::Ptxt< CKKS >::convertToSlot (
            const Context & ,
            long slot )
```

7.132.4.12 convertToSlot() [2/3]

```
PolyMod helib::Ptxt< BGV >::convertToSlot (
            const Context & context,
            long slot )
```

7.132.4.13 convertToSlot() [3/3]

```
static SlotType helib::Ptxt::convertToSlot (
            const Context & context,
            long slot ) [static]
```

Conversion function from `long` to `SlotType`.

Parameters

context	Context which may be needed to extract algebraic info.
slot	Datum to be converted to a `SlotType`.

Returns

Converted slot.

7.132.4.14 cube()

```
Ptxt< Scheme > & helib::Ptxt::cube ( )
```

Cube operation on a `Ptxt`.

Returns

Reference to `*this` post cube operation.

7.132.4.15 decodeSetData() [1/2]

```
void helib::Ptxt< BGV >::decodeSetData (
            const NTL::ZZX & data )
```

7.132.4.16 decodeSetData() [2/2]

```
template<typename T = Scheme, typename std::enable_if_t< std::is_same< T, BGV >::value > * =
nullptr>
void helib::Ptxt::decodeSetData (
            const NTL::ZZX & data )
```

Set the `Ptxt` slots using values from decoding `data` to slot representation.

Parameters

data	Polynomial to be decoded and converted into slot data.

Note

Only works in the BGV case.

7.132.4.17 frobeniusAutomorph() [1/2]

```
template<typename T = Scheme, std::enable_if_t< std::is_same< T, BGV >::value > * = nullptr>
Ptxt<Scheme>& helib::Ptxt::frobeniusAutomorph (
            long j )
```

Apply the frobenius automorphism a(X) -> a(X^(p^j)) mod Phi_m(X).

Parameters

j	Exponent of the automorphism to apply.

Returns

Reference to `*this` post frobenius automorphism application.

Note

Only valid for the BGV scheme.

7.132.4.18 frobeniusAutomorph() [2/2]

```
Ptxt< BGV > & helib::Ptxt< BGV >::frobeniusAutomorph (
            long j )
```

7.132.4.19 getPolyRepr() [1/3]

`NTL::ZZX helib::Ptxt< BGV >::getPolyRepr ( ) const`

BGV specialisation of the `getPolyRepr` function.

Returns

Single encoded polynomial.

Note

Only enabled for the `BGV` scheme.

7.132.4.20 getPolyRepr() [2/3]

`NTL::ZZX helib::Ptxt< CKKS >::getPolyRepr ( ) const`

CKKS specialisation of the `getPolyRepr` function.

Returns

Single encoded polynomial.

Note

Only enabled for the `CKKS` scheme.

7.132.4.21 getPolyRepr() [3/3]

`NTL::ZZX helib::Ptxt::getPolyRepr ( ) const`

Converts the slot data in `this` to its single polynomial representation.

Returns

Single encoded polynomial.

Note

`NTL::ZZX` representation loses some precision in the `CKKS` case.

7.132.4.22 getSlotRepr()

```
const std::vector< typename Ptxt< Scheme >::SlotType > & helib::Ptxt::getSlotRepr ( ) const
```

Get the data held in the slots as a `std::vector<SlotType>`.

Returns

Constant reference to the slot vector.

7.132.4.23 imag() [1/2]

```
template<typename T = Scheme, std::enable_if_t< std::is_same< T, CKKS >::value > * = nullptr>
Ptxt<Scheme> helib::Ptxt::imag ( ) const
```

Extract the imaginary part of a CKKS plaintext.

Returns

New plaintext containing the imaginary part of each slot.

Note

Only valid for the `CKKS` scheme.

7.132.4.24 imag() [2/2]

```
Ptxt< CKKS > helib::Ptxt< CKKS >::imag ( ) const
```

7.132.4.25 incrementalProduct()

```
Ptxt< Scheme > & helib::Ptxt::incrementalProduct ( )
```

Compute the incremental product (each slot is the product of the previous slots).

Returns

Reference to `*this` post multiplication.

7.132.4.26 isValid()

```
bool helib::Ptxt::isValid ( ) const
```

Check if a Ptxt is valid.

Returns

true if valid, false otherwise.

7.132.4.27 lsize()

```
long helib::Ptxt::lsize ( ) const
```

Returns the size (number of slots) of a Ptxt as long.

Returns

Number of slots of the Ptxt.

7.132.4.28 mapTo01()

```
Ptxt< Scheme > & helib::Ptxt::mapTo01 ( )
```

Map all non-zero slots to 1, keeping zero slots as zero.

Returns

Reference to *this post mapping.

7.132.4.29 multiplyBy()

```
Ptxt< Scheme > & helib::Ptxt::multiplyBy (
            const Ptxt< Scheme > & otherPtxt )
```

Multiplication function between two Ptxt objects.

Parameters

otherPtxt	Right hand side of multiplication.

Returns

Reference to `*this` post multiplication.

Note

This function is equivalent to operator $*=$.

7.132.4.30 multiplyBy2()

```
Ptxt< Scheme > & helib::Ptxt::multiplyBy2 (
            const Ptxt & otherPtxt1,
            const Ptxt & otherPtxt2 )
```

Multiplication function between three `Ptxt` objects.

Parameters

otherPtxt1	First `Ptxt` to multiply with.
otherPtxt2	Second `Ptxt` to multiply with.

Returns

Reference to `*this` post multiplication.

7.132.4.31 negate()

```
Ptxt< Scheme > & helib::Ptxt::negate ( )
```

Negate a `Ptxt`.

Returns

Reference to `*this` post negation.

7.132.4.32 operator"!=()

```
bool helib::Ptxt::operator!= (
            const Ptxt< Scheme > & other ) const
```

Not equals operator between two Ptxt objects.

Parameters

other	Ptxt to compare to.

Returns

`true` if differ, `false` otherwise.

7.132.4.33 operator*()

```
Ptxt< Scheme > helib::Ptxt::operator* (
            const Ptxt< Scheme > & rhs ) const
```

Infix multiplication operator.

Parameters

rhs	Right hand side of multiplication.

Returns

Product of the two Ptxt objects.

7.132.4.34 operator*=() [1/5]

```
template<typename Scheme >
Ptxt<Scheme>& helib::Ptxt::operator*= (
            const Ptxt< Scheme > & otherPtxt )
```

7.132.4.35 operator*=() [2/5]

```
Ptxt<Scheme>& helib::Ptxt::operator*= (
            const Ptxt< Scheme > & otherPtxt )
```

Times equals operator with another `Ptxt`.

Parameters

otherPtxt	Right hand side of multiplication.

Returns

Reference to `*this` post multiplication.

7.132.4.36 operator*=() [3/5]

```
template<typename Scalar >
Ptxt<Scheme>& helib::Ptxt::operator*= (
            const Scalar & scalar )  [inline]
```

Times equals operator with a scalar.

Parameters

scalar	Element to be added across all slots.

Returns

Reference to `*this` post scalar multiplication.

7.132.4.37 operator*=() [4/5]

```
template<typename Scheme >
Ptxt<Scheme>& helib::Ptxt::operator*= (
             const SlotType & scalar )
```

7.132.4.38 operator*=() [5/5]

```
Ptxt<Scheme>& helib::Ptxt::operator*= (
             const SlotType & scalar )
```

Times equals operator with a single `SlotType`.

Parameters

scalar	Element to be multiplied across all slots.

Returns

Reference to `*this` post multiplication.

7.132.4.39 operator+()

```
Ptxt< Scheme > helib::Ptxt::operator+ (
             const Ptxt< Scheme > & rhs ) const
```

Infix addition operator.

Parameters

rhs	Right hand side of addition.

Returns

Sum of the two `Ptxt` objects.

7.132.4.40 operator+=() [1/5]

```
template<typename Scheme >
Ptxt<Scheme>& helib::Ptxt::operator+= (
            const Ptxt< Scheme > & otherPtxt )
```

7.132.4.41 operator+=() [2/5]

```
Ptxt<Scheme>& helib::Ptxt::operator+= (
            const Ptxt< Scheme > & otherPtxt )
```

Plus equals operator with another `Ptxt`.

Parameters

otherPtxt	Right hand side of addition.

Returns

Reference to `*this` post addition.

7.132.4.42 operator+=() [3/5]

```
template<typename Scalar >
Ptxt<Scheme>& helib::Ptxt::operator+= (
            const Scalar & scalar ) [inline]
```

Plus equals operator with a scalar.

Parameters

scalar	Element to be added across all slots.

Returns

Reference to `*this` post scalar addition.

7.132.4.43 operator+=() [4/5]

```
template<typename Scheme >
Ptxt<Scheme>& helib::Ptxt::operator+= (
            const SlotType & scalar )
```

7.132.4.44 operator+=() [5/5]

```
Ptxt<Scheme>& helib::Ptxt::operator+= (
            const SlotType & scalar )
```

Plus equals operator with a single `SlotType`.

Parameters

scalar	Element to be added across all slots.

Returns

Reference to `*this` post addition.

7.132.4.45 operator-()

```
Ptxt< Scheme > helib::Ptxt::operator- (
            const Ptxt< Scheme > & rhs ) const
```

Infix subtraction operator.

Parameters

rhs	Right hand side of subtraction.

Returns

Difference of the two `Ptxt` objects.

7.132.4.46 operator-=() [1/5]

```
template<typename Scheme >
Ptxt<Scheme>& helib::Ptxt::operator-= (
            const Ptxt< Scheme > & otherPtxt )
```

7.132.4.47 operator-=() [2/5]

```
Ptxt<Scheme>& helib::Ptxt::operator-= (
            const Ptxt< Scheme > & otherPtxt )
```

Minus equals operator with another `Ptxt`.

Parameters

otherPtxt	Right hand side of subtraction.

Returns

Reference to `*this` post subtraction.

7.132.4.48 operator-=() [3/5]

```
template<typename Scalar >
Ptxt<Scheme>& helib::Ptxt::operator-= (
            const Scalar & scalar ) [inline]
```

Minus equals operator with a scalar.

Parameters

scalar	Element to be subtracted across all slots.

Returns

Reference to `*this` post scalar subtraction.

7.132.4.49 operator-=() [4/5]

```
template<typename Scheme >
Ptxt<Scheme>& helib::Ptxt::operator-= (
            const SlotType & scalar )
```

7.132.4.50 operator-=() [5/5]

```
Ptxt<Scheme>& helib::Ptxt::operator-= (
            const SlotType & scalar )
```

Minus equals operator with a single `SlotType`.

Parameters

scalar	Element to be subtracted across all slots.

Returns

Reference to `*this` post subtraction.

7.132.4.51 operator=() [1/2]

```
Ptxt<Scheme>& helib::Ptxt::operator= (
            const Ptxt< Scheme > & v )  [default]
```

Copy assignment operator with other `Ptxt`.

Parameters

other	`Ptxt` to copy.

7.132.4.52 operator=() [2/2]

```
Ptxt<Scheme>& helib::Ptxt::operator= (
            Ptxt< Scheme > && v )  [default], [noexcept]
```

Move assignment operator with other `Ptxt`.

Parameters

other	`Ptxt` to copy.

7.132.4.53 operator==()

```
bool helib::Ptxt::operator== (
            const Ptxt< Scheme > & other ) const
```

Equals operator between two `Ptxt` objects.

Parameters

other	`Ptxt` to compare to.

Returns

`true` if identical, `false` otherwise.

7.132.4.54 operator[]() [1/2]

```
Ptxt< Scheme >::SlotType & helib::Ptxt::operator[] (
            long i )
```

Square bracket accessor operator.

Parameters

i	Index of the desired `Ptxt` slot.

Returns

Reference to the data held at slot `i`.

7.132.4.55 operator[]() [2/2]

```
Ptxt< Scheme >::SlotType helib::Ptxt::operator[] (
            long i ) const
```

`const` square bracket accessor operator.

Parameters

i	Index of the desired `Ptxt` slot.

Returns

Copy of the data held at slot `i`.

7.132.4.56 power()

```
Ptxt< Scheme > & helib::Ptxt::power (
            long e )
```

Power operation to raise a `Ptxt` to an arbitrary non-negative power.

Parameters

e	Exponent to raise the `Ptxt` by.

Returns

Reference to `*this` post raising to the power e.

7.132.4.57 random()

```
Ptxt< Scheme > & helib::Ptxt::random ( )
```

Populate slots with random data.

Returns

Reference to `*this` post population.

7.132.4.58 real() [1/2]

```
template<typename T = Scheme, std::enable_if_t< std::is_same< T, CKKS >::value > * = nullptr>
Ptxt<Scheme> helib::Ptxt::real ( ) const
```

Extract the real part of a CKKS plaintext.

Returns

New plaintext containing the real part of each slot.

Note

Only valid for the `CKKS` scheme.

7.132.4.59 real() [2/2]

```
Ptxt< CKKS > helib::Ptxt< CKKS >::real ( ) const
```

7.132.4.60 replicate()

```
Ptxt< Scheme > & helib::Ptxt::replicate (
            long pos )
```

Replicate single slot across all slots.

Parameters

pos	Position of the slot to replicate.

Returns

Reference to `*this` post replication.

7.132.4.61 replicateAll()

```
std::vector< Ptxt< Scheme > > helib::Ptxt::replicateAll ( ) const
```

Generate a vector of plaintexts with each slot replicated in each plaintext.

Returns

Vector of replicated plaintext slots. The order of the return vector agrees with the order of the slots. i.e. the i-th plaintext in the return value is a replication of `*this[i]`.

7.132.4.62 rotate()

```
Ptxt< Scheme > & helib::Ptxt::rotate (
            long amount )
```

Rotate slots right by specified amount (slot `i` goes to slot `i+1 mod size`).

Parameters

amount	Number of slots to rotate by.

Returns

Reference to `*this` post rotation.

7.132.4.63 rotate1D()

```
Ptxt< Scheme > & helib::Ptxt::rotate1D (
            long dim,
            long amount )
```

Rotate slots right by specified amount along a specific dimension.

Parameters

dim	Dimension in which to rotate.
amount	Number of slots to rotate by.

Returns

Reference to `*this` post rotation.

7.132.4.64 runningSums()

```
Ptxt< Scheme > & helib::Ptxt::runningSums ( )
```

Compute the running sum (each slot is the sum of the previous slots).

Returns

Reference to `*this` post summation.

7.132.4.65 setData() [1/6]

```
void helib::Ptxt< BGV >::setData (
            const NTL::ZZX & value )
```

7.132.4.66 setData() [2/6]

```
template<typename T = Scheme, typename std::enable_if_t< std::is_same< T, BGV >::value > * =
nullptr>
void helib::Ptxt::setData (
            const NTL::ZZX & value )
```

Set the `Ptxt` data replicating the input polynomial on all slots.

Parameters

data	Polynomial to be replicate into slots.

Note

Only works in the BGV case.

7.132.4.67 setData() [3/6]

```
template<typename Scheme >
void helib::Ptxt::setData (
              const SlotType & value )
```

7.132.4.68 setData() [4/6]

```
void helib::Ptxt::setData (
              const SlotType & value )
```

Set the data replicating the input on all slots.

Parameters

value	`value` to set all slots to.

7.132.4.69 setData() [5/6]

```
template<typename Scheme >
void helib::Ptxt::setData (
              const std::vector< SlotType > & data )
```

7.132.4.70 setData() [6/6]

```
void helib::Ptxt::setData (
            const std::vector< SlotType > & data )
```

Set the data.

Parameters

data	Vector of `SlotType` to populate the slots.

7.132.4.71 shift()

```
Ptxt< Scheme > & helib::Ptxt::shift (
            long amount )
```

Shifts slots right by specified amount with `0` fill (slot `i` goes to slot `i+1 mod size`).

Parameters

amount	Number of slots to shift by.

Returns

Reference to `*this` post shift.

7.132.4.72 shift1D()

```
Ptxt< Scheme > & helib::Ptxt::shift1D (
            long dim,
            long amount )
```

Shift slots right in one dimension of the hypercube structure with `0` fill.

Parameters

dim	Dimension in which to shift.
amount	Amount by which to shift.

Returns

Reference to `*this` post shift.

7.132.4.73 size()

```
size_t helib::Ptxt::size ( ) const
```

Returns the size (number of slots) of a `Ptxt`.

Returns

Number of slots of the `Ptxt`.

7.132.4.74 square()

```
Ptxt< Scheme > & helib::Ptxt::square ( )
```

Square operation on a `Ptxt`.

Returns

Reference to `*this` post squaring.

7.132.4.75 totalProduct()

```
Ptxt< Scheme > & helib::Ptxt::totalProduct ( )
```

Compute the total product (each slot contains the total product of every slot).

Returns

Reference to `*this` post multiplication.

7.132.4.76 totalSums()

```
Ptxt< Scheme > & helib::Ptxt::totalSums ( )
```

Compute the total sum (each slot contains the total sum of every slot).

Returns

Reference to `*this` post summation.

7.132.5 Friends And Related Function Documentation

7.132.5.1 operator<<

```
std::ostream& operator<< (
            std::ostream & os,
            const Ptxt< Scheme > & ptxt )   [friend]
```

Output shift operator.

Parameters

os	Output `std::ostream`.
ptxt	`Ptxt` object to be written.

Returns

Input `std::ostream` post writing.

Note

`Ptxt` `context` is not serialised, see note of `operator>>`.

7.132.5.2 operator>>

```
std::istream& operator>> (
            std::istream & is,
            Ptxt< Scheme > & ptxt )   [friend]
```

Input shift operator.

Parameters

is	Input std::istream.
ptxt	Destination Ptxt object.

Returns

Input `std::istream` post reading.

Note

`ptxt` must be constructed with an appropriate context **BEFORE** calling this function. For example,

```
Ptxt my_ptxt(context);
std::cin » my_ptxt;
```

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

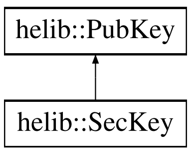
- /HElib/include/helib/Ctxt.h
- /HElib/include/helib/Ptxt.h
- /HElib/src/Ptxt.cpp

7.133 helib::PubKey Class Reference

The public key.

`#include <keys.h>`

Inheritance diagram for helib::PubKey:



Public Member Functions

- PubKey ()
  This constructor thorws run-time error if activeContext=nullptr.
- PubKey (const Context &_context)
- PubKey (const PubKey &other)
  Copy constructor.
- virtual ~PubKey ()=default
  Default destructor.
- virtual void clear ()
  Clear all public-key data.

- bool operator== (const PubKey &other) const
- bool operator!= (const PubKey &other) const
- const Context & getContext () const
- long getPtxtSpace () const
- bool keyExists (long keyID) const
- double getSKeyBound (long keyID=0) const

  The size of the secret key.
- bool isReachable (long k, long keyID=0) const

  Is it possible to re-linearize the automorphism X -> X^k See Section 3.2.2 in the design document (KeySwitchMap)
- void setKeySwitchMap (long keyId=0)

  Compute the reachability graph of key-switching matrices See Section 3.2.2 in the design document (KeySwitchMap)
- long getKSStrategy (long dim) const

  get KS strategy for dimension dim dim == -1 is Frobenius
- void setKSStrategy (long dim, int val)

  set KS strategy for dimension dim dim == -1 is Frobenius
- long Encrypt (Ctxt &ciphertxt, const NTL::ZZX &plaintxt, long ptxtSpace, bool highNoise) const
- long Encrypt (Ctxt &ciphertxt, const zzX &plaintxt, long ptxtSpace, bool highNoise) const
- void CKKSencrypt (Ctxt &ciphertxt, const NTL::ZZX &plaintxt, double ptxtSize=1.0, double scaling=0.0) const
- void CKKSencrypt (Ctxt &ciphertxt, const zzX &plaintxt, double ptxtSize=1.0, double scaling=0.0) const
- virtual long Encrypt (Ctxt &ciphertxt, const NTL::ZZX &plaintxt, long ptxtSpace=0) const
- virtual long Encrypt (Ctxt &ciphertxt, const zzX &plaintxt, long ptxtSpace=0) const
- template<typename Scheme >

  long Encrypt (Ctxt &ciphertxt, const Ptxt< Scheme > &plaintxt, long ptxtSpace=0) const

  Encrypts a plaintext into a ciphertext.
- bool isCKKS () const
- bool isBootstrappable () const
- void reCrypt (Ctxt &ctxt) const
- void thinReCrypt (Ctxt &ctxt) const
- friend void ::helib::writePubKeyBinary (std::ostream &str, const PubKey &pk)
- friend void ::helib::readPubKeyBinary (std::istream &str, PubKey &pk)
- void hackPtxtSpace (long p2r)
- template<> long Encrypt (Ctxt &ciphertxt, const Ptxt< BGV > &plaintxt, long ptxtSpace) const
- template<> long Encrypt (Ctxt &ciphertxt, const Ptxt< CKKS > &plaintxt, UNUSED long ptxtSpace) const

Find key-switching matrices

- const std::vector< KeySwitch > & keySWlist () const
- const KeySwitch & getKeySWmatrix (const SKHandle &from, long toID=0) const

  Find a key-switching matrix by its indexes. If no such matrix exists it returns a dummy matrix with toKeyID==-1.
- const KeySwitch & getKeySWmatrix (long fromSPower, long fromXPower, long fromID=0, long toID=0) const
- bool haveKeySWmatrix (const SKHandle &from, long toID=0) const
- bool haveKeySWmatrix (long fromSPower, long fromXPower, long fromID=0, long toID=0) const
- const KeySwitch & getAnyKeySWmatrix (const SKHandle &from) const

  Is there a matrix from this key to any base key?
- bool haveAnyKeySWmatrix (const SKHandle &from) const
- const KeySwitch & getNextKSWmatrix (long fromXPower, long fromID=0) const

  Get the next matrix to use for multi-hop automorphism See Section 3.2.2 in the design document.

Static Public Member Functions

- static long ePlusR (long p)

Friends

- class SecKey
- std::ostream & operator<< (std::ostream &str, const PubKey &pk)
- std::istream & operator>> (std::istream &str, PubKey &pk)

7.133.1 Detailed Description

The public key.

7.133.2 Constructor & Destructor Documentation

7.133.2.1 PubKey() [1/3]

```
helib::PubKey::PubKey ( )
```

This constructor thorws run-time error if activeContext=nullptr.

7.133.2.2 PubKey() [2/3]

```
helib::PubKey::PubKey (
            const Context & _context )  [explicit]
```

7.133.2.3 PubKey() [3/3]

```
helib::PubKey::PubKey (
            const PubKey & other )
```

Copy constructor.

7.133.2.4 ~PubKey()

```
virtual helib::PubKey::~PubKey ( )  [virtual], [default]
```

Default destructor.

7.133.3 Member Function Documentation

7.133.3.1 CKKSencrypt() [1/2]

```
void helib::PubKey::CKKSencrypt (
            Ctxt & ciphertxt,
            const NTL::ZZX & plaintxt,
            double ptxtSize = 1.0,
            double scaling = 0.0 ) const
```

7.133.3.2 CKKSencrypt() [2/2]

```
void helib::PubKey::CKKSencrypt (
            Ctxt & ciphertxt,
            const zzX & plaintxt,
            double ptxtSize = 1.0,
            double scaling = 0.0 ) const
```

7.133.3.3 clear()

```
void helib::PubKey::clear ( )  [virtual]
```

Clear all public-key data.

Reimplemented in helib::SecKey.

7.133.3.4 Encrypt() [1/7]

```
long helib::PubKey::Encrypt (
            Ctxt & ciphertxt,
            const NTL::ZZX & plaintxt,
            long ptxtSpace,
            bool highNoise ) const
```

Encrypts plaintext, result returned in the ciphertext argument. When called with highNoise=true, returns a ciphertext with noise level approximately q/8. For BGV, ptxtSpace is the intended plaintext space, which cannot be co-prime with pubEncrKey.ptxtSpace. The returned value is the plaintext-space for the resulting ciphertext, which is G↩CD(ptxtSpace, pubEncrKey.ptxtSpace). For CKKS, ptxtSpace is a bound on the size of the complex plaintext elements that are encoded in ptxt (before scaling), it is assumed that they are scaled by context.alMod.encode↩ScalingFactor(). The returned value is the same as the argument ptxtSpace.

7.133.3.5 Encrypt() [2/7]

```
long helib::PubKey::Encrypt (
            Ctxt & ciphertxt,
            const NTL::ZZX & plaintxt,
            long ptxtSpace = 0 ) const [virtual]
```

Reimplemented in helib::SecKey.

7.133.3.6 Encrypt() [3/7]

```
template<>
long helib::PubKey::Encrypt (
            Ctxt & ciphertxt,
            const Ptxt< BGV > & plaintxt,
            long ptxtSpace ) const
```

7.133.3.7 Encrypt() [4/7]

```
template<>
long helib::PubKey::Encrypt (
            Ctxt & ciphertxt,
            const Ptxt< CKKS > & plaintxt,
            UNUSED long ptxtSpace ) const
```

7.133.3.8 Encrypt() [5/7]

```
template<typename Scheme >
long helib::PubKey::Encrypt (
            Ctxt & ciphertxt,
            const Ptxt< Scheme > & plaintxt,
            long ptxtSpace = 0 ) const
```

Encrypts a plaintext into a ciphertext.

Template Parameters

Scheme	Encryption scheme used (must be BGV or CKKS).

Parameters

ciphertxt	Ciphertext into which to encrypt.
plaintxt	Plaintext to encrypt.

Returns

Plaintext space.

7.133.3.9 Encrypt() [6/7]

```
long helib::PubKey::Encrypt (
            Ctxt & ciphertxt,
            const zzX & plaintxt,
            long ptxtSpace,
            bool highNoise ) const
```

7.133.3.10 Encrypt() [7/7]

```
long helib::PubKey::Encrypt (
            Ctxt & ciphertxt,
            const zzX & plaintxt,
            long ptxtSpace = 0 ) const  [virtual]
```

Reimplemented in helib::SecKey.

7.133.3.11 ePlusR()

```
static long helib::PubKey::ePlusR (
            long p )  [static]
```

7.133.3.12 getAnyKeySWmatrix()

```
const KeySwitch & helib::PubKey::getAnyKeySWmatrix (
            const SKHandle & from ) const
```

Is there a matrix from this key to *any* base key?

7.133.3.13 getContext()

```
const Context & helib::PubKey::getContext ( ) const
```

7.133.3.14 getKeySWmatrix() [1/2]

```
const KeySwitch & helib::PubKey::getKeySWmatrix (
            const SKHandle & from,
            long toID = 0 ) const
```

Find a key-switching matrix by its indexes. If no such matrix exists it returns a dummy matrix with toKeyID==-1.

7.133.3.15 getKeySWmatrix() [2/2]

```
const KeySwitch & helib::PubKey::getKeySWmatrix (
            long fromSPower,
            long fromXPower,
            long fromID = 0,
            long toID = 0 ) const
```

7.133.3.16 getKSStrategy()

```
long helib::PubKey::getKSStrategy (
            long dim ) const
```

get KS strategy for dimension dim dim == -1 is Frobenius

7.133.3.17 getNextKSWmatrix()

```
const KeySwitch & helib::PubKey::getNextKSWmatrix (
            long fromXPower,
            long fromID = 0 ) const
```

Get the next matrix to use for multi-hop automorphism See Section 3.2.2 in the design document.

7.133.3.18 getPtxtSpace()

```
long helib::PubKey::getPtxtSpace ( ) const
```

7.133.3.19 getSKeyBound()

```
double helib::PubKey::getSKeyBound (
            long keyID = 0 ) const
```

The size of the secret key.

7.133.3.20 hackPtxtSpace()

```
void helib::PubKey::hackPtxtSpace (
            long p2r ) [inline]
```

7.133.3.21 haveAnyKeySWmatrix()

```
bool helib::PubKey::haveAnyKeySWmatrix (
            const SKHandle & from ) const
```

7.133.3.22 haveKeySWmatrix() [1/2]

```
bool helib::PubKey::haveKeySWmatrix (
            const SKHandle & from,
            long toID = 0 ) const
```

7.133.3.23 haveKeySWmatrix() [2/2]

```
bool helib::PubKey::haveKeySWmatrix (
            long fromSPower,
            long fromXPower,
            long fromID = 0,
            long toID = 0 ) const
```

7.133.3.24 isBootstrappable()

```
bool helib::PubKey::isBootstrappable ( ) const
```

7.133.3.25 isCKKS()

```
bool helib::PubKey::isCKKS ( ) const
```

7.133.3.26 isReachable()

```
bool helib::PubKey::isReachable (
            long k,
            long keyID = 0 ) const
```

Is it possible to re-linearize the automorphism X -> X^k See Section 3.2.2 in the design document (KeySwitchMap)

7.133.3.27 keyExists()

```
bool helib::PubKey::keyExists (
            long keyID ) const
```

7.133.3.28 keySWlist()

```
const std::vector< KeySwitch > & helib::PubKey::keySWlist ( ) const
```

7.133.3.29 operator"!=()

```
bool helib::PubKey::operator!= (
            const PubKey & other ) const
```

7.133.3.30 operator==()

```
bool helib::PubKey::operator== (
            const PubKey & other ) const
```

7.133.3.31 reCrypt()

```
void helib::PubKey::reCrypt (
            Ctxt & ctxt ) const
```

7.133.3.32 setKeySwitchMap()

```
void helib::PubKey::setKeySwitchMap (
            long keyId = 0 )
```

Compute the reachability graph of key-switching matrices See Section 3.2.2 in the design document (KeySwitch↩ Map)

7.133.3.33 setKSStrategy()

```
void helib::PubKey::setKSStrategy (
            long dim,
            int val )
```

set KS strategy for dimension dim dim == -1 is Frobenius

7.133.3.34 thinReCrypt()

```
void helib::PubKey::thinReCrypt (
            Ctxt & ctxt ) const
```

7.133.3.35 void ::helib::readPubKeyBinary()

```
helib::PubKey::void ::helib::readPubKeyBinary (
            std::istream & str,
            PubKey & pk )
```

7.133.3.36 void ::helib::writePubKeyBinary()

```
helib::PubKey::void ::helib::writePubKeyBinary (
            std::ostream & str,
            const PubKey & pk )
```

7.133.4 Friends And Related Function Documentation

7.133.4.1 operator<<

```
std::ostream& operator<< (
            std::ostream & str,
            const PubKey & pk )  [friend]
```

7.133.4.2 operator>>

```
std::istream& operator>> (
            std::istream & str,
            PubKey & pk )  [friend]
```

7.133.4.3 SecKey

```
friend class SecKey  [friend]
```

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

- /HElib/include/helib/keys.h
- /HElib/src/keys.cpp
- /HElib/src/recryption.cpp

7.134 helib::PubKeyHack Struct Reference

Public Attributes

- const Context & context
- Ctxt pubEncrKey
- std::vector< long > skHwts
- std::vector< KeySwitch > keySwitching
- std::vector< std::vector< long > > keySwitchMap
- NTL::Vec< int > KS_strategy
- long recryptKeyID
- Ctxt recryptEkey

7.134.1 Member Data Documentation

7.134.1.1 context

```
const Context& helib::PubKeyHack::context
```

7.134.1.2 keySwitching

```
std::vector<KeySwitch> helib::PubKeyHack::keySwitching
```

7.134.1.3 keySwitchMap

```
std::vector<std::vector<long> > helib::PubKeyHack::keySwitchMap
```

7.134.1.4 KS_strategy

```
NTL::Vec<int> helib::PubKeyHack::KS_strategy
```

7.134.1.5 pubEncrKey

```
Ctxt helib::PubKeyHack::pubEncrKey
```

The public encryption key is an encryption of 0, relative to the first secret key

7.134.1.6 recryptEkey

```
Ctxt helib::PubKeyHack::recryptEkey
```

7.134.1.7 recryptKeyID

```
long helib::PubKeyHack::recryptKeyID
```

7.134.1.8 skHwts

```
std::vector<long> helib::PubKeyHack::skHwts
```

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

- /HElib/src/recryption.cpp

7.135 helib::quarter_FFT Struct Reference

```
#include <PAlgebra.h>
```

Public Member Functions

- quarter_FFT (long m)

Public Attributes

- PGFFT fft
- std::vector< std::complex< double > > pow1
- std::vector< std::complex< double > > pow2

7.135.1 Constructor & Destructor Documentation

7.135.1.1 quarter_FFT()

```
helib::quarter_FFT::quarter_FFT (
            long m )
```

7.135.2 Member Data Documentation

7.135.2.1 fft

```
PGFFT helib::quarter_FFT::fft
```

7.135.2.2 pow1

```
std::vector<std::complex<double> > helib::quarter_FFT::pow1
```

7.135.2.3 pow2

```
std::vector<std::complex<double> > helib::quarter_FFT::pow2
```

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

- /HElib/include/helib/PAlgebra.h
- /HElib/src/PAlgebra.cpp

7.136 helib::random_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa)

7.136.1 Member Function Documentation

7.136.1.1 apply()

```
template<typename type >
static void helib::random_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa ) [inline], [static]
```

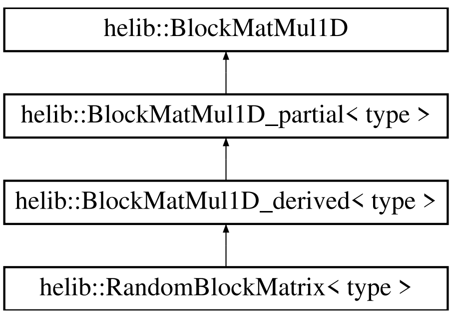
The documentation for this class was generated from the following file:

- /HElib/src/EncryptedArray.cpp

7.137 helib::RandomBlockMatrix< type > Class Template Reference

```
#include <randomMatrices.h>
```

Inheritance diagram for helib::RandomBlockMatrix< type >:



Public Member Functions

- RandomBlockMatrix (const EncryptedArray &_ea, long _dim)
- bool get (mat_R &out, long i, long j, UNUSED long k) const override
- const EncryptedArray & getEA () const override
- long getDim () const override
- bool multipleTransforms () const override

Additional Inherited Members

7.137.1 Constructor & Destructor Documentation

7.137.1.1 RandomBlockMatrix()

```
template<typename type >
helib::RandomBlockMatrix< type >::RandomBlockMatrix (
            const EncryptedArray & _ea,
            long _dim )  [inline]
```

7.137.2 Member Function Documentation

7.137.2.1 get()

```
template<typename type >
bool helib::RandomBlockMatrix< type >::get (
            mat_R & out,
            long i,
            long j,
            UNUSED long k ) const  [inline], [override]
```

7.137.2.2 getDim()

```
template<typename type >
long helib::RandomBlockMatrix< type >::getDim ( ) const  [inline], [override], [virtual]
```

Implements helib::BlockMatMul1D.

7.137.2.3 getEA()

```
template<typename type >
const EncryptedArray& helib::RandomBlockMatrix< type >::getEA ( ) const  [inline], [override],
[virtual]
```

Implements helib::BlockMatMul1D.

7.137.2.4 multipleTransforms()

```
template<typename type >
bool helib::RandomBlockMatrix< type >::multipleTransforms ( ) const [inline], [override],
[virtual]
```

Implements helib::BlockMatMul1D_derived< type >.

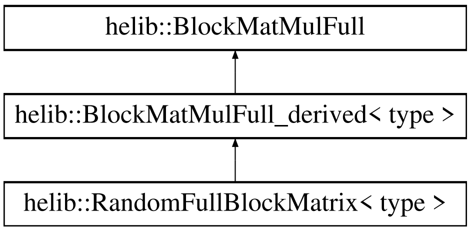
The documentation for this class was generated from the following file:

- /HElib/include/helib/randomMatrices.h

7.138 helib::RandomFullBlockMatrix< type > Class Template Reference

```
#include <randomMatrices.h>
```

Inheritance diagram for helib::RandomFullBlockMatrix< type >:



Public Member Functions

- RandomFullBlockMatrix (const EncryptedArray &_ea)
- bool get (mat_R &out, long i, long j) const override
- const EncryptedArray & getEA () const override

Additional Inherited Members

7.138.1 Constructor & Destructor Documentation

7.138.1.1 RandomFullBlockMatrix()

```
template<typename type >
helib::RandomFullBlockMatrix< type >::RandomFullBlockMatrix (
            const EncryptedArray & _ea ) [inline]
```

7.138.2 Member Function Documentation

7.138.2.1 get()

```
template<typename type >
bool helib::RandomFullBlockMatrix< type >::get (
            mat_R & out,
            long i,
            long j ) const [inline], [override], [virtual]
```

Implements helib::BlockMatMulFull_derived< type >.

7.138.2.2 getEA()

```
template<typename type >
const EncryptedArray& helib::RandomFullBlockMatrix< type >::getEA ( ) const [inline], [override],
[virtual]
```

Implements helib::BlockMatMulFull.

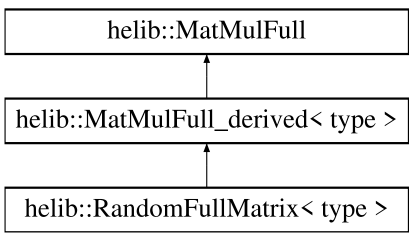
The documentation for this class was generated from the following file:

- /HElib/include/helib/randomMatrices.h

7.139 helib::RandomFullMatrix< type > Class Template Reference

```
#include <randomMatrices.h>
```

Inheritance diagram for helib::RandomFullMatrix< type >:



Public Member Functions

- RandomFullMatrix (const EncryptedArray &_ea)
- bool get (RX &out, long i, long j) const override
- const EncryptedArray & getEA () const override

Additional Inherited Members

7.139.1 Constructor & Destructor Documentation

7.139.1.1 RandomFullMatrix()

```
template<typename type >
helib::RandomFullMatrix< type >::RandomFullMatrix (
            const EncryptedArray & _ea )  [inline]
```

7.139.2 Member Function Documentation

7.139.2.1 get()

```
template<typename type >
bool helib::RandomFullMatrix< type >::get (
            RX & out,
            long i,
            long j ) const  [inline], [override], [virtual]
```

Implements helib::MatMulFull_derived< type >.

7.139.2.2 getEA()

```
template<typename type >
const EncryptedArray& helib::RandomFullMatrix< type >::getEA ( ) const  [inline], [override],
[virtual]
```

Implements helib::MatMulFull.

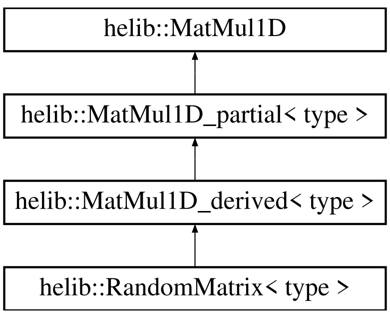
The documentation for this class was generated from the following file:

- /HElib/include/helib/randomMatrices.h

7.140 helib::RandomMatrix< type > Class Template Reference

```
#include <randomMatrices.h>
```

Inheritance diagram for helib::RandomMatrix< type >:



Public Member Functions

- virtual ~RandomMatrix ()
- RandomMatrix (const EncryptedArray &_ea, long _dim)
- const EncryptedArray & getEA () const override
- bool multipleTransforms () const override
- long getDim () const override
- bool get (RX &out, long i, long j, UNUSED long k) const override

Additional Inherited Members

7.140.1 Constructor & Destructor Documentation

7.140.1.1 ~RandomMatrix()

```
template<typename type >
virtual helib::RandomMatrix< type >::~RandomMatrix ( )  [inline], [virtual]
```

7.140.1.2 RandomMatrix()

```
template<typename type >
helib::RandomMatrix< type >::RandomMatrix (
             const EncryptedArray & _ea,
             long _dim )  [inline]
```

7.140.2 Member Function Documentation

7.140.2.1 get()

```
template<typename type >
bool helib::RandomMatrix< type >::get (
             RX & out,
             long i,
             long j,
             UNUSED long k ) const  [inline], [override]
```

7.140.2.2 getDim()

```
template<typename type >
long helib::RandomMatrix< type >::getDim ( ) const [inline], [override], [virtual]
```

Implements helib::MatMul1D.

7.140.2.3 getEA()

```
template<typename type >
const EncryptedArray& helib::RandomMatrix< type >::getEA ( ) const [inline], [override],
[virtual]
```

Implements helib::MatMul1D.

7.140.2.4 multipleTransforms()

```
template<typename type >
bool helib::RandomMatrix< type >::multipleTransforms ( ) const [inline], [override], [virtual]
```

Implements helib::MatMul1D_derived< type >.

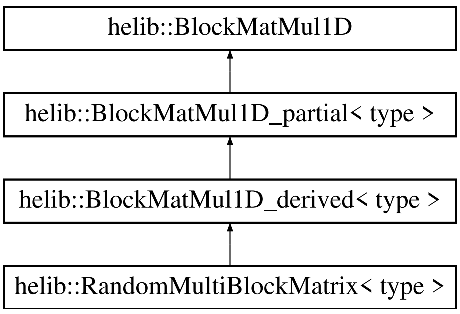
The documentation for this class was generated from the following file:

- /HElib/include/helib/randomMatrices.h

7.141 helib::RandomMultiBlockMatrix< type > Class Template Reference

```
#include <randomMatrices.h>
```

Inheritance diagram for helib::RandomMultiBlockMatrix< type >:



Public Member Functions

- RandomMultiBlockMatrix (const EncryptedArray &_ea, long _dim)
- bool get (mat_R &out, long i, long j, long k) const override
- const EncryptedArray & getEA () const override
- long getDim () const override
- bool multipleTransforms () const override

Additional Inherited Members

7.141.1 Constructor & Destructor Documentation

7.141.1.1 RandomMultiBlockMatrix()

```
template<typename type >
helib::RandomMultiBlockMatrix< type >::RandomMultiBlockMatrix (
            const EncryptedArray & _ea,
            long _dim )  [inline]
```

7.141.2 Member Function Documentation

7.141.2.1 get()

```
template<typename type >
bool helib::RandomMultiBlockMatrix< type >::get (
            mat_R & out,
            long i,
            long j,
            long k ) const  [inline], [override], [virtual]
```

Implements helib::BlockMatMul1D_derived< type >.

7.141.2.2 getDim()

```
template<typename type >
long helib::RandomMultiBlockMatrix< type >::getDim ( ) const  [inline], [override], [virtual]
```

Implements helib::BlockMatMul1D.

7.141.2.3 getEA()

```
template<typename type >
const EncryptedArray& helib::RandomMultiBlockMatrix< type >::getEA ( ) const [inline], [override],
[virtual]
```

Implements helib::BlockMatMul1D.

7.141.2.4 multipleTransforms()

```
template<typename type >
bool helib::RandomMultiBlockMatrix< type >::multipleTransforms ( ) const [inline], [override],
[virtual]
```

Implements helib::BlockMatMul1D_derived< type >.

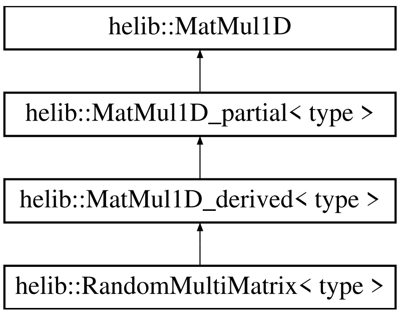
The documentation for this class was generated from the following file:

- /HElib/include/helib/randomMatrices.h

7.142 helib::RandomMultiMatrix< type > Class Template Reference

```
#include <randomMatrices.h>
```

Inheritance diagram for helib::RandomMultiMatrix< type >:



Public Member Functions

- virtual ~RandomMultiMatrix ()
- RandomMultiMatrix (const EncryptedArray &_ea, long _dim)
- const EncryptedArray & getEA () const override
- bool multipleTransforms () const override
- long getDim () const override
- bool get (RX &out, long i, long j, long k) const override

Additional Inherited Members

7.142.1 Constructor & Destructor Documentation

7.142.1.1 ∼RandomMultiMatrix()

```
template<typename type >
virtual helib::RandomMultiMatrix< type >::~RandomMultiMatrix ( ) [inline], [virtual]
```

7.142.1.2 RandomMultiMatrix()

```
template<typename type >
helib::RandomMultiMatrix< type >::RandomMultiMatrix (
            const EncryptedArray & _ea,
            long _dim ) [inline]
```

7.142.2 Member Function Documentation

7.142.2.1 get()

```
template<typename type >
bool helib::RandomMultiMatrix< type >::get (
            RX & out,
            long i,
            long j,
            long k ) const [inline], [override], [virtual]
```

Implements helib::MatMul1D_derived< type >.

7.142.2.2 getDim()

```
template<typename type >
long helib::RandomMultiMatrix< type >::getDim ( ) const [inline], [override], [virtual]
```

Implements helib::MatMul1D.

7.142.2.3 getEA()

```
template<typename type >
const EncryptedArray& helib::RandomMultiMatrix< type >::getEA ( ) const [inline], [override],
[virtual]
```

Implements helib::MatMul1D.

7.142.2.4 multipleTransforms()

```
template<typename type >
bool helib::RandomMultiMatrix< type >::multipleTransforms ( ) const [inline], [override],
[virtual]
```

Implements helib::MatMul1D_derived< type >.

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

- /HElib/include/helib/randomMatrices.h

7.143 helib::RandomState Class Reference

Facility for "restoring" the NTL PRG state.

`#include <NumbTh.h>`

Public Member Functions

- RandomState ()
- void restore ()

  Restore the PRG state of NTL.
- ∼RandomState ()

7.143.1 Detailed Description

Facility for "restoring" the NTL PRG state.

NTL's random number generation facility is pretty limited, and does not provide a way to save/restore the state of a pseudo-random stream. This class gives us that ability: Constructing a RandomState object uses the PRG to generate 512 bits and stores them. Upon destruction (or an explicit call to restore()), these bits are used to re-set the seed of the PRG. A typical usage of the class is as follows:

```
{
  RandomState r;        // save the random state
  SetSeed(something); // set the PRG seed to something
  ...                   // more code that uses the new PRG seed
} // The destructor is called implicitly, PRG state is restored
```

7.143.2 Constructor & Destructor Documentation

7.143.2.1 RandomState()

```
helib::RandomState::RandomState ( ) [inline]
```

7.143.2.2 ∼RandomState()

```
helib::RandomState::~RandomState ( ) [inline]
```

7.143.3 Member Function Documentation

7.143.3.1 restore()

```
void helib::RandomState::restore ( ) [inline]
```

Restore the PRG state of NTL.

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

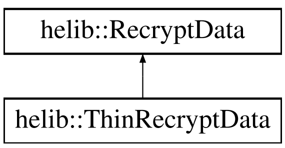
- /HElib/include/helib/NumbTh.h

7.144 helib::RecryptData Class Reference

A structure to hold recryption-related data inside the Context.

```
#include <recryption.h>
```

Inheritance diagram for helib::RecryptData:



Public Member Functions

- RecryptData ()
- void init (const Context &context, const NTL::Vec< long > &mvec_, bool enableThick, long t=0, bool build_cache=false, bool minimal=false)

  Initialize the recryption data in the context.
- bool operator== (const RecryptData &other) const
- bool operator!= (const RecryptData &other) const

Static Public Member Functions

- static long setAE (long &e, long &ePrime, const Context &context, long t=0)

  Helper function for computing the recryption parameters.

Public Attributes

- NTL::Vec< long > mvec

  Some data members that are only used for I/O.
- long e

  partition of m into co-prime factors
- long ePrime
- long skHwt

  Hamming weight of recryption secret key.
- std::shared_ptr< const PAlgebraMod > alMod

  for plaintext space p^{e-e'+r}
- std::shared_ptr< const EncryptedArray > ea

  for plaintext space p^{e-e'+r}
- bool build_cache
- std::shared_ptr< const EvalMap > firstMap

  linear maps
- std::shared_ptr< const EvalMap > secondMap
- std::shared_ptr< const PowerfulDCRT > p2dConv

  conversion between ZZX and Powerful
- std::vector< NTL::ZZX > unpackSlotEncoding

  linPolys for unpacking the slots

Static Public Attributes

- static constexpr long defSkHwt = 100

  default Hamming weight of recryption key

7.144.1 Detailed Description

A structure to hold recryption-related data inside the Context.

7.144.2 Constructor & Destructor Documentation

7.144.2.1 RecryptData()

```
helib::RecryptData::RecryptData ( ) [inline]
```

7.144.3 Member Function Documentation

7.144.3.1 init()

```
void helib::RecryptData::init (
            const Context & context,
            const NTL::Vec< long > & mvec_,
            bool enableThick,
            long t = 0,
            bool build_cache = false,
            bool minimal = false )
```

Initialize the recryption data in the context.

7.144.3.2 operator"!=()

```
bool helib::RecryptData::operator!= (
            const RecryptData & other ) const [inline]
```

7.144.3.3 operator==()

```
bool helib::RecryptData::operator== (
            const RecryptData & other ) const
```

7.144.3.4 setAE()

```
long helib::RecryptData::setAE (
            long & e,
            long & ePrime,
            const Context & context,
            long t = 0 ) [static]
```

Helper function for computing the recryption parameters.

7.144.4 Member Data Documentation

7.144.4.1 alMod

`std::shared_ptr<const PAlgebraMod> helib::RecryptData::alMod`

for plaintext space p^{e-e'+r}

7.144.4.2 build_cache

`bool helib::RecryptData::build_cache`

7.144.4.3 defSkHwt

`constexpr long helib::RecryptData::defSkHwt = 100 [static], [constexpr]`

default Hamming weight of recryption key

7.144.4.4 e

`long helib::RecryptData::e`

partition of m into co-prime factors

skey encrypted wrt space p^{e-e'+r}

7.144.4.5 ea

`std::shared_ptr<const EncryptedArray> helib::RecryptData::ea`

for plaintext space p^{e-e'+r}

7.144.4.6 ePrime

`long helib::RecryptData::ePrime`

7.144.4.7 firstMap

`std::shared_ptr<const EvalMap> helib::RecryptData::firstMap`

linear maps

7.144.4.8 mvec

`NTL::Vec<long> helib::RecryptData::mvec`

Some data members that are only used for I/O.

7.144.4.9 p2dConv

`std::shared_ptr<const PowerfulDCRT> helib::RecryptData::p2dConv`

conversion between ZZX and Powerful

7.144.4.10 secondMap

`std::shared_ptr<const EvalMap> helib::RecryptData::secondMap`

7.144.4.11 skHwt

`long helib::RecryptData::skHwt`

Hamming weight of recryption secret key.

7.144.4.12 unpackSlotEncoding

`std::vector<NTL::ZZX> helib::RecryptData::unpackSlotEncoding`

linPolys for unpacking the slots

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

- /HElib/include/helib/recryption.h
- /HElib/src/recryption.cpp

7.145 helib::replicate_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, long i)

7.145.1 Member Function Documentation

7.145.1.1 apply()

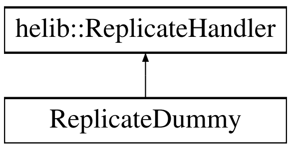
```
template<typename type >
static void helib::replicate_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            long i )  [inline], [static]
```

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

- /HElib/src/replicate.cpp

7.146 ReplicateDummy Class Reference

Inheritance diagram for ReplicateDummy:



Public Member Functions

- ReplicateDummy ()
- virtual void handle (const Ctxt &ctxt)

7.146.1 Constructor & Destructor Documentation

7.146.1.1 ReplicateDummy()

```
ReplicateDummy::ReplicateDummy ( )  [inline]
```

7.146.2 Member Function Documentation

7.146.2.1 handle()

```
virtual void ReplicateDummy::handle (
            const Ctxt & ctxt ) [inline], [virtual]
```

Implements helib::ReplicateHandler.

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

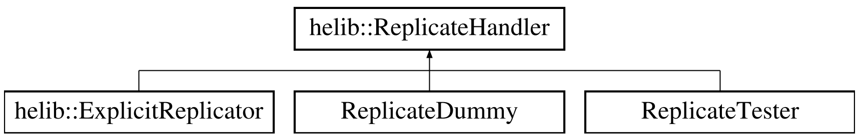
- /HElib/src/Test_Timing.cpp

7.147 helib::ReplicateHandler Class Reference

An abstract class to handle call-backs to get the output of replicate.

```
#include <replicate.h>
```

Inheritance diagram for helib::ReplicateHandler:



Public Member Functions

- virtual void handle (const Ctxt &ctxt)=0
- virtual ∼ReplicateHandler ()
- virtual bool earlyStop (long d, long k, long prodDim)

7.147.1 Detailed Description

An abstract class to handle call-backs to get the output of replicate.

7.147.2 Constructor & Destructor Documentation

7.147.2.1 ∼ReplicateHandler()

```
virtual helib::ReplicateHandler::∼ReplicateHandler ( ) [inline], [virtual]
```

7.147.3 Member Function Documentation

7.147.3.1 earlyStop()

```
virtual bool helib::ReplicateHandler::earlyStop (
            long d,
            long k,
            long prodDim )  [inline], [virtual]
```

7.147.3.2 handle()

```
virtual void helib::ReplicateHandler::handle (
            const Ctxt & ctxt )  [pure virtual]
```

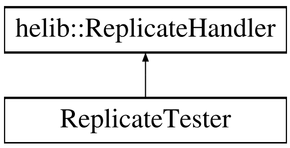
Implemented in helib::ExplicitReplicator, ReplicateDummy, and ReplicateTester.

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

- /HElib/include/helib/replicate.h

7.148 ReplicateTester Class Reference

Inheritance diagram for ReplicateTester:



Public Member Functions

- ReplicateTester (const SecKey &_sKey, const EncryptedArray &_ea, const PlaintextArray &_pa, long _B)
- virtual void handle (const Ctxt &ctxt)

Public Attributes

- const SecKey & sKey
- const EncryptedArray & ea
- const PlaintextArray & pa
- long B
- double t_last
- double t_total
- long pos
- bool error

7.148.1 Constructor & Destructor Documentation

7.148.1.1 ReplicateTester()

```
ReplicateTester::ReplicateTester (
            const SecKey & _sKey,
            const EncryptedArray & _ea,
            const PlaintextArray & _pa,
            long _B )  [inline]
```

7.148.2 Member Function Documentation

7.148.2.1 handle()

```
virtual void ReplicateTester::handle (
            const Ctxt & ctxt )  [inline], [virtual]
```

Implements helib::ReplicateHandler.

7.148.3 Member Data Documentation

7.148.3.1 B

```
long ReplicateTester::B
```

7.148.3.2 ea

```
const EncryptedArray& ReplicateTester::ea
```

7.148.3.3 error

```
bool ReplicateTester::error
```

7.148.3.4 pa

```
const PlaintextArray& ReplicateTester::pa
```

7.148.3.5 pos

```
long ReplicateTester::pos
```

7.148.3.6 sKey

```
const SecKey& ReplicateTester::sKey
```

7.148.3.7 t_last

```
double ReplicateTester::t_last
```

7.148.3.8 t_total

```
double ReplicateTester::t_total
```

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

- /HElib/src/Test_Replicate.cpp

7.149 helib::rotate_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, long k)

7.149.1 Member Function Documentation

7.149.1.1 apply()

```
template<typename type >
static void helib::rotate_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            long k ) [inline], [static]
```

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

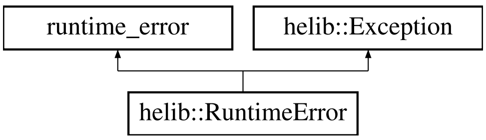
- /HElib/src/EncryptedArray.cpp

7.150 helib::RuntimeError Class Reference

Inherits from Exception and std::runtime_error.

`#include <exceptions.h>`

Inheritance diagram for helib::RuntimeError:



Public Member Functions

- RuntimeError (const std::string &what_arg)
- RuntimeError (const char ∗what_arg)
- virtual ∼RuntimeError ()
- virtual const char ∗ what () const noexcept override

Additional Inherited Members

7.150.1 Detailed Description

Inherits from Exception and std::runtime_error.

7.150.2 Constructor & Destructor Documentation

7.150.2.1 RuntimeError() [1/2]

```
helib::RuntimeError::RuntimeError (
            const std::string & what_arg )  [inline], [explicit]
```

7.150.2.2 RuntimeError() [2/2]

```
helib::RuntimeError::RuntimeError (
            const char * what_arg )  [inline], [explicit]
```

7.150.2.3 ∼RuntimeError()

```
virtual helib::RuntimeError::~RuntimeError ( )  [inline], [virtual]
```

7.150.3 Member Function Documentation

7.150.3.1 what()

```
virtual const char* helib::RuntimeError::what ( ) const  [inline], [override], [virtual], [noexcept]
```

Implements helib::Exception.

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

- /HElib/include/helib/exceptions.h

7.151 helib::ScratchCell Class Reference

A class to help manage the allocation of temporary Ctxt objects.

Public Member Functions

- ScratchCell (const Ctxt &c)
- ScratchCell (ScratchCell &&other)

Public Attributes

- std::atomic_bool used
- std::unique_ptr< Ctxt > ct

7.151.1 Detailed Description

A class to help manage the allocation of temporary Ctxt objects.

7.151.2 Constructor & Destructor Documentation

7.151.2.1 ScratchCell() [1/2]

```
helib::ScratchCell::ScratchCell (
            const Ctxt & c )  [inline]
```

7.151.2.2 ScratchCell() [2/2]

```
helib::ScratchCell::ScratchCell (
            ScratchCell && other )  [inline]
```

7.151.3 Member Data Documentation

7.151.3.1 ct

```
std::unique_ptr<Ctxt> helib::ScratchCell::ct
```

7.151.3.2 used

```
std::atomic_bool helib::ScratchCell::used
```

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

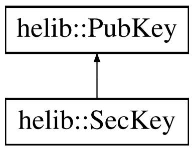
- /HElib/src/binaryArith.cpp

7.152 helib::SecKey Class Reference

The secret key.

```
#include <keys.h>
```

Inheritance diagram for helib::SecKey:



Public Member Functions

- SecKey ()=delete
- ∼SecKey () override=default
- SecKey (const Context &_context)
- bool operator== (const SecKey &other) const
- bool operator!= (const SecKey &other) const
- void clear () override

  Clear all secret-key data.
- long ImportSecKey (const DoubleCRT &sKey, double bound, long ptxtSpace=0, long maxDegKswitch=3)
- long GenSecKey (long hwt=0, long ptxtSpace=0, long maxDegKswitch=3)
- void GenKeySWmatrix (long fromSPower, long fromXPower, long fromKeyIdx=0, long toKeyIdx=0, long ptxt↩ Space=0)
- void Decrypt (NTL::ZZX &plaintxt, const Ctxt &ciphertxt) const
- template<typename Scheme >
  void Decrypt (Ptxt< Scheme > &plaintxt, const Ctxt &ciphertxt) const

  Decrypt a ciphertext into a plaintext.
- void Decrypt (NTL::ZZX &plaintxt, const Ctxt &ciphertxt, NTL::ZZX &f) const

  Debugging version, returns in f the polynomial before reduction modulo the ptxtSpace.
- long skEncrypt (Ctxt &ctxt, const NTL::ZZX &ptxt, long ptxtSpace, long skIdx) const

  Symmetric encryption using the secret key.
- long skEncrypt (Ctxt &ctxt, const zzX &ptxt, long ptxtSpace, long skIdx) const
- long Encrypt (Ctxt &ciphertxt, const NTL::ZZX &plaintxt, long ptxtSpace=0) const override
- long Encrypt (Ctxt &ciphertxt, const zzX &plaintxt, long ptxtSpace=0) const override
- long genRecryptData ()

  Generate bootstrapping data if needed, returns index of key.
- friend void ::helib::writeSecKeyBinary (std::ostream &str, const SecKey &sk)
- friend void ::helib::readSecKeyBinary (std::istream &str, SecKey &sk)
- template<> void Decrypt (Ptxt< BGV > &plaintxt, const Ctxt &ciphertxt) const
- template<> void Decrypt (Ptxt< CKKS > &plaintxt, const Ctxt &ciphertxt) const

Public Attributes

- std::vector< DoubleCRT > sKeys

Friends

- std::ostream & operator<< (std::ostream &str, const SecKey &sk)
- std::istream & operator>> (std::istream &str, SecKey &sk)

Additional Inherited Members

7.152.1 Detailed Description

The secret key.

7.152.2 Constructor & Destructor Documentation

7.152.2.1 SecKey() [1/2]

```
helib::SecKey::SecKey ( ) [delete]
```

7.152.2.2 ~SecKey()

```
helib::SecKey::~SecKey ( ) [override], [default]
```

7.152.2.3 SecKey() [2/2]

```
helib::SecKey::SecKey (
            const Context & _context ) [explicit]
```

7.152.3 Member Function Documentation

7.152.3.1 clear()

```
void helib::SecKey::clear ( ) [override], [virtual]
```

Clear all secret-key data.

Reimplemented from helib::PubKey.

7.152.3.2 Decrypt() [1/5]

```
void helib::SecKey::Decrypt (
            NTL::ZZX & plaintxt,
            const Ctxt & ciphertxt ) const
```

7.152.3.3 Decrypt() [2/5]

```
void helib::SecKey::Decrypt (
            NTL::ZZX & plaintxt,
            const Ctxt & ciphertxt,
            NTL::ZZX & f ) const
```

Debugging version, returns in f the polynomial before reduction modulo the ptxtSpace.

7.152.3.4 Decrypt() [3/5]

```
template<>
void helib::SecKey::Decrypt (
            Ptxt< BGV > & plaintxt,
            const Ctxt & ciphertxt ) const
```

7.152.3.5 Decrypt() [4/5]

```
template<>
void helib::SecKey::Decrypt (
            Ptxt< CKKS > & plaintxt,
            const Ctxt & ciphertxt ) const
```

7.152.3.6 Decrypt() [5/5]

```
template<typename Scheme >
void helib::SecKey::Decrypt (
            Ptxt< Scheme > & plaintxt,
            const Ctxt & ciphertxt ) const
```

Decrypt a ciphertext into a plaintext.

Template Parameters

Scheme	Encryption scheme used (must be BGV or CKKS).

Parameters

plaintxt	Plaintext into which to decrypt.
ciphertxt	Ciphertext to decrypt.

7.152.3.7 Encrypt() [1/2]

```
long helib::SecKey::Encrypt (
            Ctxt & ciphertxt,
            const NTL::ZZX & plaintxt,
            long ptxtSpace = 0 ) const  [override], [virtual]
```

Reimplemented from helib::PubKey.

7.152.3.8 Encrypt() [2/2]

```
long helib::SecKey::Encrypt (
            Ctxt & ciphertxt,
            const zzX & plaintxt,
            long ptxtSpace = 0 ) const  [override], [virtual]
```

Reimplemented from helib::PubKey.

7.152.3.9 GenKeySWmatrix()

```
void helib::SecKey::GenKeySWmatrix (
            long fromSPower,
            long fromXPower,
            long fromKeyIdx = 0,
            long toKeyIdx = 0,
            long ptxtSpace = 0 )
```

Generate a key-switching matrix and store it in the public key. The i'th column of the matrix encrypts fromKey∗↩ B1∗B2∗...∗B{i-1}∗Q under toKey, relative to the largest modulus (i.e., all primes) and plaintext space p. Q is the product of special primes, and the Bi's are the products of primes in the i'th digit. The plaintext space defaults to 2^r, as defined by context.mod2r.

7.152.3.10 genRecryptData()

```
long helib::SecKey::genRecryptData ( )
```

Generate bootstrapping data if needed, returns index of key.

7.152.3.11 GenSecKey()

```
long helib::SecKey::GenSecKey (
            long hwt = 0,
            long ptxtSpace = 0,
            long maxDegKswitch = 3 )
```

Key generation: This procedure generates a single secret key, pushes it onto the sKeys list using ImportSecKey from above.

7.152.3.12 ImportSecKey()

```
long helib::SecKey::ImportSecKey (
            const DoubleCRT & sKey,
            double bound,
            long ptxtSpace = 0,
            long maxDegKswitch = 3 )
```

We allow the calling application to choose a secret-key polynomial by itself, then insert it into the SecKey object, getting the index of that secret key in the sKeys list. If this is the first secret-key for this object then the procedure below also generates a corresponding public encryption key. It is assumed that the context already contains all parameters.

7.152.3.13 operator"!=()

```
bool helib::SecKey::operator!= (
            const SecKey & other ) const
```

7.152.3.14 operator==()

```
bool helib::SecKey::operator== (
            const SecKey & other ) const
```

7.152.3.15 skEncrypt() [1/2]

```
long helib::SecKey::skEncrypt (
            Ctxt & ctxt,
            const NTL::ZZX & ptxt,
            long ptxtSpace,
            long skIdx ) const
```

Symmetric encryption using the secret key.

7.152.3.16 skEncrypt() [2/2]

```
long helib::SecKey::skEncrypt (
            Ctxt & ctxt,
            const zzX & ptxt,
            long ptxtSpace,
            long skIdx ) const
```

7.152.3.17 void ::helib::readSecKeyBinary()

```
helib::SecKey::void ::helib::readSecKeyBinary (
            std::istream & str,
            SecKey & sk )
```

7.152.3.18 void ::helib::writeSecKeyBinary()

```
helib::SecKey::void ::helib::writeSecKeyBinary (
            std::ostream & str,
            const SecKey & sk )
```

7.152.4 Friends And Related Function Documentation

7.152.4.1 operator<<

```
std::ostream& operator<< (
            std::ostream & str,
            const SecKey & sk ) [friend]
```

7.152.4.2 operator>>

```
std::istream& operator>> (
            std::istream & str,
            SecKey & sk ) [friend]
```

7.152.5 Member Data Documentation

7.152.5.1 sKeys

```
std::vector<DoubleCRT> helib::SecKey::sKeys
```

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

- /HElib/include/helib/keys.h
- /HElib/src/keys.cpp

7.153 helib::shallow_clone< X > Class Template Reference

Shallow copy: initialize with copy constructor.

```
#include <clonedPtr.h>
```

Static Public Member Functions

- static X ∗ apply (const X ∗x)

7.153.1 Detailed Description

template<typename X>
class helib::shallow_clone< X >

Shallow copy: initialize with copy constructor.

Template Parameters

X	The class to which this points

7.153.2 Member Function Documentation

7.153.2.1 apply()

```
template<typename X >
static X* helib::shallow_clone< X >::apply (
            const X * x ) [inline], [static]
```

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

- /HElib/include/helib/clonedPtr.h

7.154 helib::shift_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, long k)

7.154.1 Member Function Documentation

7.154.1.1 apply()

```
template<typename type >
static void helib::shift_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            long k ) [inline], [static]
```

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

- /HElib/src/EncryptedArray.cpp

7.155 helib::SKHandle Class Reference

A handle, describing the secret-key element that "matches" a part, of the form s^r(X^t).

```
#include <Ctxt.h>
```

Public Member Functions

- SKHandle (long newPowerOfS=0, long newPowerOfX=1, long newSecretKeyID=0)
- void setBase (long newSecretKeyID=-1)

  Set powerOfS=powerOfX=1.
- bool isBase (long ofKeyID=0) const

  Is powerOfS==powerOfX==1?
- void setOne (long newSecretKeyID=-1)

  Set powerOfS=0, powerOfX=1.
- bool isOne () const

  Is powerOfS==0?
- bool operator== (const SKHandle &other) const
- bool operator!= (const SKHandle &other) const
- long getPowerOfS () const
- long getPowerOfX () const
- long getSecretKeyID () const
- bool mul (const SKHandle &a, const SKHandle &b)

  Computes the "product" of two handles.
- void read (std::istream &str)
- void write (std::ostream &str) const

Friends

- class Ctxt
- std::istream & operator>> (std::istream &s, SKHandle &handle)

7.155.1 Detailed Description

A handle, describing the secret-key element that "matches" a part, of the form s^r(X^t).

7.155.2 Constructor & Destructor Documentation

7.155.2.1 SKHandle()

```
helib::SKHandle::SKHandle (
            long newPowerOfS = 0,
            long newPowerOfX = 1,
            long newSecretKeyID = 0 )  [inline]
```

7.155.3 Member Function Documentation

7.155.3.1 getPowerOfS()

```
long helib::SKHandle::getPowerOfS ( ) const [inline]
```

7.155.3.2 getPowerOfX()

```
long helib::SKHandle::getPowerOfX ( ) const [inline]
```

7.155.3.3 getSecretKeyID()

```
long helib::SKHandle::getSecretKeyID ( ) const [inline]
```

7.155.3.4 isBase()

```
bool helib::SKHandle::isBase (
            long ofKeyID = 0 ) const [inline]
```

Is powerOfS==powerOfX==1?

7.155.3.5 isOne()

```
bool helib::SKHandle::isOne ( ) const [inline]
```

Is powerOfS==0?

7.155.3.6 mul()

```
bool helib::SKHandle::mul (
            const SKHandle & a,
            const SKHandle & b ) [inline]
```

Computes the "product" of two handles.

The key-ID's and powers of X must match, else an error state arises, which is represented using a key-ID of -1 and returning false. Also, note that inputs may alias outputs.

To determine if the resulting handle can be re-linearized using some key-switching matrices from the public key, use the method pubKey.haveKeySWmatrix(handle,handle.secretKeyID), from the class PubKey in keys.h

7.155.3.7 operator"!=()

```
bool helib::SKHandle::operator!= (
            const SKHandle & other ) const  [inline]
```

7.155.3.8 operator==()

```
bool helib::SKHandle::operator== (
            const SKHandle & other ) const  [inline]
```

7.155.3.9 read()

```
void helib::SKHandle::read (
            std::istream & str )
```

7.155.3.10 setBase()

```
void helib::SKHandle::setBase (
            long newSecretKeyID = -1 )  [inline]
```

Set powerOfS=powerOfX=1.

7.155.3.11 setOne()

```
void helib::SKHandle::setOne (
            long newSecretKeyID = -1 )  [inline]
```

Set powerOfS=0, powerOfX=1.

7.155.3.12 write()

```
void helib::SKHandle::write (
            std::ostream & str ) const
```

7.155.4 Friends And Related Function Documentation

7.155.4.1 Ctxt

```
friend class Ctxt [friend]
```

7.155.4.2 operator>>

```
std::istream& operator>> (
            std::istream & s,
            SKHandle & handle ) [friend]
```

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

- /HElib/include/helib/Ctxt.h
- /HElib/src/Ctxt.cpp

7.156 StopReplicate Class Reference

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

- /HElib/src/Test_Replicate.cpp

7.157 helib::sub_pa_impl< type > Class Template Reference

Static Public Member Functions

- static void apply (const EncryptedArrayDerived< type > &ea, PlaintextArray &pa, const PlaintextArray &other)

7.157.1 Member Function Documentation

7.157.1.1 apply()

```
template<typename type >
static void helib::sub_pa_impl< type >::apply (
            const EncryptedArrayDerived< type > & ea,
            PlaintextArray & pa,
            const PlaintextArray & other ) [inline], [static]
```

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

- /HElib/src/EncryptedArray.cpp

7.158 helib::SubDimension Class Reference

A node in a tree relative to some generator.

```
#include <permutations.h>
```

Public Member Functions

- SubDimension (long sz=0, bool gd=false, long ee=0, const NTL::Vec< long > &bns1=dummyBenes, const NTL::Vec< long > &bns2=dummyBenes)
- long totalLength () const

Public Attributes

- long size
- bool good
- long e
- NTL::Vec< long > frstBenes
- NTL::Vec< long > scndBenes

Friends

- std::ostream & operator<< (std::ostream &s, const SubDimension &tree)

7.158.1 Detailed Description

A node in a tree relative to some generator.

7.158.2 Constructor & Destructor Documentation

7.158.2.1 SubDimension()

```
helib::SubDimension::SubDimension (
            long sz = 0,
            bool gd = false,
            long ee = 0,
            const NTL::Vec< long > & bns1 = dummyBenes,
            const NTL::Vec< long > & bns2 = dummyBenes )  [inline], [explicit]
```

7.158.3 Member Function Documentation

7.158.3.1 totalLength()

```
long helib::SubDimension::totalLength ( ) const  [inline]
```

7.158.4 Friends And Related Function Documentation

7.158.4.1 operator<<

```
std::ostream& operator<< (
            std::ostream & s,
            const SubDimension & tree )  [friend]
```

7.158.5 Member Data Documentation

7.158.5.1 e

```
long helib::SubDimension::e
```

7.158.5.2 frstBenes

```
NTL::Vec<long> helib::SubDimension::frstBenes
```

7.158.5.3 good

```
bool helib::SubDimension::good
```

7.158.5.4 scndBenes

```
NTL::Vec<long> helib::SubDimension::scndBenes
```

7.158.5.5 size

```
long helib::SubDimension::size
```

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

- /HElib/include/helib/permutations.h
- /HElib/src/permutations.cpp

7.159 helib::ThinEvalMap Class Reference

Class that provides the functionality for the linear transforms used in "thin" boostrapping, where slots are assumed to contain constants. The interface is exactly the same as for EvalMap, except that the constructor does not have a normal_basis parameter.

```
#include <EvalMap.h>
```

Public Member Functions

- ThinEvalMap (const EncryptedArray &_ea, bool minimal, const NTL::Vec< long > &mvec, bool _invert, bool build_cache)
- void upgrade ()
- void apply (Ctxt &ctxt) const

7.159.1 Detailed Description

Class that provides the functionality for the linear transforms used in "thin" boostrapping, where slots are assumed to contain constants. The interface is exactly the same as for EvalMap, except that the constructor does not have a normal_basis parameter.

7.159.2 Constructor & Destructor Documentation

7.159.2.1 ThinEvalMap()

```
helib::ThinEvalMap::ThinEvalMap (
            const EncryptedArray & _ea,
            bool minimal,
            const NTL::Vec< long > & mvec,
            bool _invert,
            bool build_cache )
```

7.159.3 Member Function Documentation

7.159.3.1 apply()

```
void helib::ThinEvalMap::apply (
            Ctxt & ctxt ) const
```

7.159.3.2 upgrade()

```
void helib::ThinEvalMap::upgrade ( )
```

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

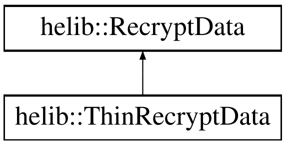
- /HElib/include/helib/EvalMap.h
- /HElib/src/EvalMap.cpp

7.160 helib::ThinRecryptData Class Reference

Same as above, but for "thin" bootstrapping, where the slots are assumed to contain constants.

```
#include <recryption.h>
```

Inheritance diagram for helib::ThinRecryptData:



Public Member Functions

- void init (const Context &context, const NTL::Vec< long > &mvec_, bool alsoThick, long t=0, bool build_cache=false, bool minimal=false)

  Initialize the recryption data in the context.

Public Attributes

- std::shared_ptr< const ThinEvalMap > coeffToSlot

  linear maps
- std::shared_ptr< const ThinEvalMap > slotToCoeff

Additional Inherited Members

7.160.1 Detailed Description

Same as above, but for "thin" bootstrapping, where the slots are assumed to contain constants.

7.160.2 Member Function Documentation

7.160.2.1 init()

```
void helib::ThinRecryptData::init (
            const Context & context,
            const NTL::Vec< long > & mvec_,
            bool alsoThick,
            long t = 0,
            bool build_cache = false,
            bool minimal = false )
```

Initialize the recryption data in the context.

7.160.3 Member Data Documentation

7.160.3.1 coeffToSlot

```
std::shared_ptr<const ThinEvalMap> helib::ThinRecryptData::coeffToSlot
```

linear maps

7.160.3.2 slotToCoeff

```
std::shared_ptr<const ThinEvalMap> helib::ThinRecryptData::slotToCoeff
```

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

- /HElib/include/helib/recryption.h
- /HElib/src/recryption.cpp

7.161 TimingData Class Reference

Public Member Functions

- TimingData (long _m=-1)

Public Attributes

- long m
- long phim
- long nSlots
- long p
- vector< LowLvlTimingData > lowLvl
- HighLvlTimingData highLvl
- OtherTimingData other

7.161.1 Constructor & Destructor Documentation

7.161.1.1 TimingData()

```
TimingData::TimingData (
            long _m = -1 )  [inline], [explicit]
```

7.161.2 Member Data Documentation

7.161.2.1 highLvl

```
HighLvlTimingData TimingData::highLvl
```

7.161.2.2 lowLvl

```
vector<LowLvlTimingData> TimingData::lowLvl
```

7.161.2.3 m

```
long TimingData::m
```

7.161.2.4 nSlots

```
long TimingData::nSlots
```

7.161.2.5 other

```
OtherTimingData TimingData::other
```

7.161.2.6 p

```
long TimingData::p
```

7.161.2.7 phim

```
long TimingData::phim
```

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

- /HElib/src/Test_Timing.cpp

7.162 helib::TreeNode< T > Class Template Reference

A node in a full binary tree.

```
#include <permutations.h>
```

Public Member Functions

- TreeNode ()
- TreeNode (const T &d)
- T & getData ()
- const T & getData () const
- long getParent () const
- long getLeftChild () const
- long getRightChild () const
- long getPrev () const
- long getNext () const

Friends

- class FullBinaryTree< T >

7.162.1 Detailed Description

template<typename T>
class helib::TreeNode< T >

A node in a full binary tree.

These nodes are in a std::vector, so we use indexes rather than pointers

7.162.2 Constructor & Destructor Documentation

7.162.2.1 TreeNode() [1/2]

```
template<typename T >
helib::TreeNode< T >::TreeNode ( )  [inline]
```

7.162.2.2 TreeNode() [2/2]

```
template<typename T >
helib::TreeNode< T >::TreeNode (
            const T & d )  [inline], [explicit]
```

7.162.3 Member Function Documentation

7.162.3.1 getData() [1/2]

```
template<typename T >
T& helib::TreeNode< T >::getData ( )  [inline]
```

7.162.3.2 getData() [2/2]

```
template<typename T >
const T& helib::TreeNode< T >::getData ( ) const  [inline]
```

7.162.3.3 getLeftChild()

```
template<typename T >
long helib::TreeNode< T >::getLeftChild ( ) const [inline]
```

7.162.3.4 getNext()

```
template<typename T >
long helib::TreeNode< T >::getNext ( ) const [inline]
```

7.162.3.5 getParent()

```
template<typename T >
long helib::TreeNode< T >::getParent ( ) const [inline]
```

7.162.3.6 getPrev()

```
template<typename T >
long helib::TreeNode< T >::getPrev ( ) const [inline]
```

7.162.3.7 getRightChild()

```
template<typename T >
long helib::TreeNode< T >::getRightChild ( ) const [inline]
```

7.162.4 Friends And Related Function Documentation

7.162.4.1 FullBinaryTree< T >

```
template<typename T >
friend class FullBinaryTree< T > [friend]
```

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

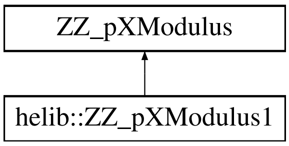
- /HElib/include/helib/permutations.h

7.163 helib::ZZ_pXModulus1 Class Reference

placeholder for pXModulus ...no optimizations

`#include <NumbTh.h>`

Inheritance diagram for helib::ZZ_pXModulus1:



Public Member Functions

- ZZ_pXModulus1 (UNUSED long _m, const NTL::ZZ_pX &_f)
- const NTL::ZZ_pXModulus & upcast () const

7.163.1 Detailed Description

placeholder for pXModulus ...no optimizations

7.163.2 Constructor & Destructor Documentation

7.163.2.1 ZZ_pXModulus1()

```
helib::ZZ_pXModulus1::ZZ_pXModulus1 (
            UNUSED long _m,
            const NTL::ZZ_pX & _f )  [inline]
```

7.163.3 Member Function Documentation

7.163.3.1 upcast()

```
const NTL::ZZ_pXModulus& helib::ZZ_pXModulus1::upcast ( ) const  [inline]
```

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

- /HElib/include/helib/NumbTh.h

7.164 helib::zz_pXModulus1 Class Reference

Auxiliary classes to facilitate faster reduction mod Phi_m(X) when the input has degree less than m.

```
#include <NumbTh.h>
```

Public Member Functions

- zz_pXModulus1 (long _m, const NTL::zz_pX &_f)
- const NTL::zz_pXModulus & upcast () const

Public Attributes

- long m
- NTL::zz_pX f
- long n
- bool specialLogic
- long k
- long k1
- NTL::fftRep R0
- NTL::fftRep R1
- NTL::zz_pXModulus fm

7.164.1 Detailed Description

Auxiliary classes to facilitate faster reduction mod Phi_m(X) when the input has degree less than m.

7.164.2 Constructor & Destructor Documentation

7.164.2.1 zz_pXModulus1()

```
helib::zz_pXModulus1::zz_pXModulus1 (
            long _m,
            const NTL::zz_pX & _f )
```

7.164.3 Member Function Documentation

7.164.3.1 upcast()

```
const NTL::zz_pXModulus& helib::zz_pXModulus1::upcast ( ) const  [inline]
```

7.164.4 Member Data Documentation

7.164.4.1 f

`NTL::zz_pX helib::zz_pXModulus1::f`

7.164.4.2 fm

`NTL::zz_pXModulus helib::zz_pXModulus1::fm`

7.164.4.3 k

`long helib::zz_pXModulus1::k`

7.164.4.4 k1

`long helib::zz_pXModulus1::k1`

7.164.4.5 m

`long helib::zz_pXModulus1::m`

7.164.4.6 n

`long helib::zz_pXModulus1::n`

7.164.4.7 R0

`NTL::fftRep helib::zz_pXModulus1::R0`

7.164.4.8 R1

`NTL::fftRep helib::zz_pXModulus1::R1`

7.164.4.9 specialLogic

`bool helib::zz_pXModulus1::specialLogic`

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

- /HElib/include/helib/NumbTh.h
- /HElib/src/NumbTh.cpp

Chapter 8

File Documentation

8.1 mainpage.dox File Reference

8.2 /HElib/include/helib/apiAttributes.h File Reference

Namespaces

- helib

Macros

- #define UNUSED

8.2.1 Macro Definition Documentation

8.2.1.1 UNUSED

```
#define UNUSED
```

8.3 /HElib/include/helib/ArgMap.h File Reference

Easier arg parsing.

```
#include <iostream>
#include <iomanip>
#include <forward_list>
#include <initializer_list>
#include <set>
#include <unordered_map>
#include <algorithm>
#include <functional>
#include <string>
#include <sstream>
#include <fstream>
#include <cctype>
#include <memory>
#include <vector>
#include <tuple>
#include <type_traits>
#include <regex>
#include <helib/assertions.h>
```

Classes

- class helib::ArgMap

  Basic class for arg parsing. Example use:
- struct helib::ArgMap::ArgProcessor

Namespaces

- helib

8.3.1 Detailed Description

Easier arg parsing.

8.4 /HElib/include/helib/assertions.h File Reference

Various assertion functions for use within HElib. These are meant as a replacement for C-style asserts, which (undesirably) exit the process without giving the opportunity to clean up and shut down gracefully. Instead, these functions will throw an exception if their conditions are violated.

```
#include <helib/exceptions.h>
```

Namespaces

- helib

Functions

- template<typename ExceptionTy = ::helib::LogicError, typename T = void>
  void helib::assertTrue (const T &value, const std::string &message)
- template<typename ExceptionTy = ::helib::LogicError, typename T = void>
  void helib::assertFalse (T value, const std::string &message)
- template<typename ExceptionTy = ::helib::LogicError, typename T = void>
  void helib::assertEq (const T &a, const T &b, const std::string &message)
- template<typename ExceptionTy = ::helib::LogicError, typename T = void>
  void helib::assertNeq (const T &a, const T &b, const std::string &message)
- template<typename ExceptionTy = ::helib::LogicError, typename T = void>
  void helib::assertNotNull (const T &p, const std::string &message)
- template<typename ExceptionTy = ::helib::OutOfRangeError, typename T = void>
  void helib::assertInRange (const T &elem, const T &min, const T &max, const std::string &message, bool right_inclusive=false)

8.4.1 Detailed Description

Various assertion functions for use within HElib. These are meant as a replacement for C-style asserts, which (undesirably) exit the process without giving the opportunity to clean up and shut down gracefully. Instead, these functions will throw an exception if their conditions are violated.

General usage is of the form:

```
helib::assertEq(my_variable, 5l, "my_variable must equal 5!");
```

Most of these functions will result in an `helib::LogicError` being thrown if their conditions are violated, except for `assertInRange`, which will throw an `helib::OutOfRange`. However, if one wishes to throw some other helib exception, one can specify it as a template argument as follows. For example:

```
helib::assertTrue<helib::InvalidArgument>(some_var > 0, "some_var must be
positive!");
```

The full set of helib exceptions can be found in exceptions.h.

8.5 /HElib/include/helib/binaryArith.h File Reference

Implementing integer addition, multiplication in binary representation.

```
#include <helib/EncryptedArray.h>
#include <helib/CtPtrs.h>
```

Namespaces

- helib

Functions

- std::vector< long > helib::longToBitVector (long num, long bitSize)

  Returns a number as a vector of bits with LSB on the left.
- void helib::binaryCond (CtPtrs &output, const Ctxt &cond, const CtPtrs &trueValue, const CtPtrs &falseValue)

  Implementation of `output = cond * trueValue + (1 - cond) * falseValue`.
- void helib::binaryMask (CtPtrs &binaryNums, const Ctxt &mask)

  Zeroes the slots of `binaryNums` *where the corresponding slot of* `mask` *is 0.*
- void helib::concatBinaryNums (CtPtrs &output, const CtPtrs &a, const CtPtrs &b)

  Concatenates two binary numbers into a single `CtPtrs` *object. E.g. If* `a=10111, b=00101` *then* `output = 1011100101`.
- void helib::splitBinaryNums (CtPtrs &leftSplit, CtPtrs &rightSplit, const CtPtrs &input)

  Splits a single binary number into two binary numbers `leftSplit` *and* `rightSplit`.
- void helib::leftBitwiseShift (CtPtrs &output, const CtPtrs &input, const long shamt)

  Left shift `input` *by* `shamt`.
- void helib::bitwiseRotate (CtPtrs &output, const CtPtrs &input, long rotamt)

  Rotate `input` *by* `rotamt`.
- void helib::bitwiseXOR (CtPtrs &output, const CtPtrs &lhs, const CtPtrs &rhs)

  Compute a bitwise XOR between `lhs` *and* `rhs`.
- void helib::bitwiseOr (CtPtrs &output, const CtPtrs &lhs, const CtPtrs &rhs)

  Compute a bitwise OR between `lhs` *and* `rhs`.
- void helib::bitwiseAnd (CtPtrs &output, const CtPtrs &lhs, const CtPtrs &rhs)

  Compute a bitwise AND between `lhs` *and* `rhs`.
- void helib::bitwiseAnd (CtPtrs &output, const CtPtrs &input, const std::vector< long > mask)

  Compute a bitwise AND between `input` *and a* `std::vector<long>`.
- void helib::bitwiseNot (CtPtrs &output, const CtPtrs &input)

  Compute a bitwise NOT of `input`.
- void helib::addTwoNumbers (CtPtrs &sum, const CtPtrs &lhs, const CtPtrs &rhs, long sizeLimit=0, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Adds two numbers in binary representation where each ciphertext of the input vector contains a bit.
- void helib::negateBinary (CtPtrs &negation, const CtPtrs &input)

  Negates a number in binary 2's complement representation.
- void helib::subtractBinary (CtPtrs &difference, const CtPtrs &lhs, const CtPtrs &rhs, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Subtracts `rhs` *from* `lhs` *where* `lhs, rhs` *are in 2's complement.*
- long helib::fifteenOrLess4Four (const CtPtrs &out, const CtPtrs &in, long sizeLimit=4)

  Add together up to fifteen {0,1} integers, producing a 4-bit counter.
- void helib::addManyNumbers (CtPtrs &sum, CtPtrMat &numbers, long sizeLimit=0, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Sum an arbitrary amount of numbers in binary representation.
- void helib::multTwoNumbers (CtPtrs &product, const CtPtrs &lhs, const CtPtrs &rhs, bool rhsTwosComplement=false, long sizeLimit=0, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Multiply two numbers in binary representation where each ciphertext of the input vector contains a bit.
- void helib::decryptBinaryNums (std::vector< long > &pNums, const CtPtrs &eNums, const SecKey &sKey, const EncryptedArray &ea, bool twosComplement=false, bool allSlots=true)

  Decrypt the binary numbers that are encrypted in eNums.
- void helib::packedRecrypt (const CtPtrs &a, const CtPtrs &b, std::vector< zzX > *unpackSlotEncoding)

  Function for packed recryption to recrypt multiple numbers.

8.5.1 Detailed Description

Implementing integer addition, multiplication in binary representation.

8.6 /HElib/include/helib/binaryCompare.h File Reference

Implementing integer comparison in binary representation.

```
#include <helib/EncryptedArray.h>
#include <helib/CtPtrs.h>
```

Namespaces

- helib

Functions

- void helib::compareTwoNumbers (CtPtrs &max, CtPtrs &min, Ctxt &mu, Ctxt &ni, const CtPtrs &a, const CtPtrs &b, bool twosComplement=false, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Compares two integers in binary `a, b`*. Returns* `max(a, b), min(a, b)` *and indicator bits* `mu`*=(a>b) and* `ni`*=(a<b)*
- void helib::compareTwoNumbers (Ctxt &mu, Ctxt &ni, const CtPtrs &a, const CtPtrs &b, bool twos←Complement=false, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Compares two integers in binary `a, b`*. Returns only indicator bits* `mu`*=(a>b) and* `ni`*=(a<b).*

8.6.1 Detailed Description

Implementing integer comparison in binary representation.

8.7 /HElib/include/helib/binio.h File Reference

```
#include <iostream>
#include <vector>
#include <type_traits>
#include <NTL/xdouble.h>
#include <NTL/vec_long.h>
```

Namespaces

- helib

Macros

- #define BINIO_32BIT 4
- #define BINIO_48BIT 6
- #define BINIO_64BIT 8
- #define BINIO_EYE_SIZE 4
- #define BINIO_EYE_CONTEXTBASE_BEGIN "|BS["
- #define BINIO_EYE_CONTEXTBASE_END "]BS|"
- #define BINIO_EYE_CONTEXT_BEGIN "|CN["
- #define BINIO_EYE_CONTEXT_END "]CN|"
- #define BINIO_EYE_CTXT_BEGIN "|CX["
- #define BINIO_EYE_CTXT_END "]CX|"
- #define BINIO_EYE_PK_BEGIN "|PK["
- #define BINIO_EYE_PK_END "]PK|"
- #define BINIO_EYE_SK_BEGIN "|SK["
- #define BINIO_EYE_SK_END "]SK|"
- #define BINIO_EYE_SKM_BEGIN "|KM["
- #define BINIO_EYE_SKM_END "]KM|"

Functions

- int helib::readEyeCatcher (std::istream &str, const char ∗expect)
- void helib::writeEyeCatcher (std::ostream &str, const char ∗eye)
- void helib::write_ntl_vec_long (std::ostream &str, const NTL::vec_long &vl, long intSize=BINIO_64BIT)
- void helib::read_ntl_vec_long (std::istream &str, NTL::vec_long &vl)
- long helib::read_raw_int (std::istream &str)
- int helib::read_raw_int32 (std::istream &str)
- void helib::write_raw_int (std::ostream &str, long num)
- void helib::write_raw_int32 (std::ostream &str, int num)
- void helib::write_raw_double (std::ostream &str, const double d)
- double helib::read_raw_double (std::istream &str)
- void helib::write_raw_xdouble (std::ostream &str, const NTL::xdouble xd)
- NTL::xdouble helib::read_raw_xdouble (std::istream &str)
- void helib::write_raw_ZZ (std::ostream &str, const NTL::ZZ &zz)
- void helib::read_raw_ZZ (std::istream &str, NTL::ZZ &zz)
- template<typename T >
  void helib::write_raw_vector (std::ostream &str, const std::vector< T > &v)
- template<> void helib::write_raw_vector< long > (std::ostream &str, const std::vector< long > &v)
- template<> void helib::write_raw_vector< double > (std::ostream &str, const std::vector< double > &v)
- template<typename T >
  void helib::read_raw_vector (std::istream &str, std::vector< T > &v, T &init)
- template<typename T >
  void helib::read_raw_vector (std::istream &str, std::vector< T > &v)
- template<> void helib::read_raw_vector< long > (std::istream &str, std::vector< long > &v)
- template<> void helib::read_raw_vector< double > (std::istream &str, std::vector< double > &v)
- template<typename T >
  void helib::read_raw_vector (std::istream &str, std::vector< T > &v, const Context &context)

8.7.1 Macro Definition Documentation

8.7.1.1 BINIO_32BIT

```
#define BINIO_32BIT 4
```

8.7.1.2 BINIO_48BIT

```
#define BINIO_48BIT 6
```

8.7.1.3 BINIO_64BIT

```
#define BINIO_64BIT 8
```

8.7.1.4 BINIO_EYE_CONTEXT_BEGIN

```
#define BINIO_EYE_CONTEXT_BEGIN "|CN["
```

8.7.1.5 BINIO_EYE_CONTEXT_END

```
#define BINIO_EYE_CONTEXT_END "]CN|"
```

8.7.1.6 BINIO_EYE_CONTEXTBASE_BEGIN

```
#define BINIO_EYE_CONTEXTBASE_BEGIN "|BS["
```

8.7.1.7 BINIO_EYE_CONTEXTBASE_END

```
#define BINIO_EYE_CONTEXTBASE_END "]BS|"
```

8.7.1.8 BINIO_EYE_CTXT_BEGIN

```
#define BINIO_EYE_CTXT_BEGIN "|CX["
```

8.7.1.9 BINIO_EYE_CTXT_END

```
#define BINIO_EYE_CTXT_END "]CX|"
```

8.7.1.10 BINIO_EYE_PK_BEGIN

```
#define BINIO_EYE_PK_BEGIN "|PK["
```

8.7.1.11 BINIO_EYE_PK_END

```
#define BINIO_EYE_PK_END "]PK|"
```

8.7.1.12 BINIO_EYE_SIZE

```
#define BINIO_EYE_SIZE 4
```

8.7.1.13 BINIO_EYE_SK_BEGIN

```
#define BINIO_EYE_SK_BEGIN "|SK["
```

8.7.1.14 BINIO_EYE_SK_END

```
#define BINIO_EYE_SK_END "]SK|"
```

8.7.1.15 BINIO_EYE_SKM_BEGIN

```
#define BINIO_EYE_SKM_BEGIN "|KM["
```

8.7.1.16 BINIO_EYE_SKM_END

```
#define BINIO_EYE_SKM_END "]KM|"
```

8.8 /HElib/include/helib/bluestein.h File Reference

declaration of BluesteinFFT(x, n, root, powers, powers_aux, Rb):

```
#include <helib/NumbTh.h>
```

Namespaces

- helib

Functions

- void helib::BluesteinInit (long n, const NTL::zz_p &root, NTL::zz_pX &powers, NTL::Vec< NTL::mulmod_precon_t > &powers_aux, NTL::fftRep &Rb)

    initialize bluestein
- void helib::BluesteinFFT (NTL::zz_pX &x, long n, const NTL::zz_p &root, const NTL::zz_pX &powers, const NTL::Vec< NTL::mulmod_precon_t > &powers_aux, const NTL::fftRep &Rb)

    apply bluestein

8.8.1 Detailed Description

declaration of BluesteinFFT(x, n, root, powers, powers_aux, Rb):

Compute length-n FFT of the coefficient-vector of x (in place) If the degree of x is less than n then it treats the top coefficients as 0, if the degree of x is more than n then the extra coefficients are ignored. Similarly, if the top entries in x are zeros then x will have degree smaller than n. The argument root is a 2n-th root of unity, namely BluesteinFFT(...,root,...)=DFT(...,root^2,...).

The inverse-FFT is obtained just by calling BluesteinFFT(... root^{-1}), but this procedure is *NOT SCALED*, so BluesteinFFT(x,n,root,...) and then BluesteinFFT(x,n,root^{-1},...) will result in x = n ∗ x_original

The values powers, powers_aux, and Rb must be precomputed by first calling BluesteinInit(n, root, powers, powers_aux, Rb).

8.9 /HElib/include/helib/clonedPtr.h File Reference

Implementation of smart pointers with "deep cloning" semantics.

Classes

- class helib::deep_clone< X >

    Deep copy: initialize with clone.
- class helib::shallow_clone< X >

    Shallow copy: initialize with copy constructor.

Namespaces

- helib

Macros

- #define CLONED_PTR_TEMPLATE_MEMBERS(CLONED_PTR_TYPE)
- #define CLONED_PTR_DECLARE(CLONED_PTR_TYPE, CLONED_PTR_INIT)

Functions

- template<typename X , typename Cloner >
  void helib::swap (cloned_ptr< X, Cloner > &x, cloned_ptr< X, Cloner > &y)
- template<typename X , typename Cloner >
  void helib::swap (copied_ptr< X, Cloner > &x, copied_ptr< X, Cloner > &y)

8.9.1 Detailed Description

Implementation of smart pointers with "deep cloning" semantics.

Based (loosely) on code from

```
http://github.com/yonat/smart_ptr/blob/master/cloned_ptr.h
```

8.9.2 Macro Definition Documentation

8.9.2.1 CLONED_PTR_DECLARE

```
#define CLONED_PTR_DECLARE(
               CLONED_PTR_TYPE,
               CLONED_PTR_INIT )
```

8.9.2.2 CLONED_PTR_TEMPLATE_MEMBERS

```
#define CLONED_PTR_TEMPLATE_MEMBERS(
               CLONED_PTR_TYPE )
```

Value:

```
                                                                              \
  template <typename Y>                                                       \
  CLONED_PTR_TYPE(const CLONED_PTR_TYPE<Y>& r)                                \
  {                                                                           \
    copy(r.ptr);                                                              \
  }                                                                           \
  template <typename Y>                                                       \
  CLONED_PTR_TYPE& operator=(const CLONED_PTR_TYPE<Y>& r)                     \
  {                                                                           \
    if (this != &r) {                                                         \
      delete ptr;                                                             \
      copy(r.ptr);                                                            \
    }                                                                         \
    return *this;                                                             \
  }
```

8.10 /HElib/include/helib/CModulus.h File Reference

Supports forward and backward length-m FFT transformations.

```
#include <helib/NumbTh.h>
#include <helib/PAlgebra.h>
#include <helib/bluestein.h>
#include <helib/clonedPtr.h>
```

Classes

- class helib::Cmodulus

    Provides FFT and iFFT routines modulo a single-precision prime.

Namespaces

- helib

8.10.1 Detailed Description

Supports forward and backward length-m FFT transformations.

This is a wrapper around the bluesteinFFT routines, for one modulus q.

8.11 /HElib/include/helib/Context.h File Reference

Keeps the parameters of an instance of the cryptosystem.

```
#include <helib/PAlgebra.h>
#include <helib/CModulus.h>
#include <helib/IndexSet.h>
#include <helib/recryption.h>
#include <helib/primeChain.h>
#include <helib/powerful.h>
#include <helib/apiAttributes.h>
#include <NTL/Lazy.h>
```

Classes

- class helib::Context

    Maintaining the parameters.

Namespaces

- helib

Functions

- long helib::FindM (long k, long nBits, long c, long p, long d, long s, long chosen_m, bool verbose=false)

  Returns smallest parameter m satisfying various constraints:
- void helib::writeContextBase (std::ostream &s, const Context &context)

  write [m p r gens ords] data
- void helib::readContextBase (std::istream &s, unsigned long &m, unsigned long &p, unsigned long &r, std::vector< long > &gens, std::vector< long > &ords)

  read [m p r gens ords] data, needed to construct context
- std::unique_ptr< Context > helib::buildContextFromAscii (std::istream &str)
- void helib::writeContextBaseBinary (std::ostream &str, const Context &context)

  write [m p r gens ords] data
- void helib::writeContextBinary (std::ostream &str, const Context &context)
- void helib::readContextBaseBinary (std::istream &s, unsigned long &m, unsigned long &p, unsigned long &r, std::vector< long > &gens, std::vector< long > &ords)

  read [m p r gens ords] data, needed to construct context
- std::unique_ptr< Context > helib::buildContextFromBinary (std::istream &str)
- void helib::readContextBinary (std::istream &str, Context &context)
- void helib::buildModChain (Context &context, long nBits, long nDgts=3, bool willBeBootstrappable=false, long skHwt=0, long resolution=3, long bitsInSpecialPrimes=0)
- void helib::endBuildModChain (Context &context)

Variables

- Context * helib::activeContext = nullptr

8.11.1 Detailed Description

Keeps the parameters of an instance of the cryptosystem.

8.12 /HElib/include/helib/CtPtrs.h File Reference

Unified interface for vector of pointers to ciphertexts.

```
#include <initializer_list>
#include <helib/Ctxt.h>
#include <helib/PtrVector.h>
#include <helib/PtrMatrix.h>
```

Namespaces

- helib

Typedefs

- typedef PtrVector< Ctxt > helib::CtPtrs
- typedef PtrVector_VecT< Ctxt > helib::CtPtrs_VecCt
- typedef PtrVector_vectorT< Ctxt > helib::CtPtrs_vectorCt
- typedef PtrVector_VecPt< Ctxt > helib::CtPtrs_VecPt
- typedef PtrVector_vectorPt< Ctxt > helib::CtPtrs_vectorPt
- typedef PtrVector_slice< Ctxt > helib::CtPtrs_slice
- typedef PtrMatrix< Ctxt > helib::CtPtrMat
- typedef PtrMatrix_Vec< Ctxt > helib::CtPtrMat_VecCt
- typedef PtrMatrix_vector< Ctxt > helib::CtPtrMat_vectorCt
- typedef PtrMatrix_ptVec< Ctxt > helib::CtPtrMat_ptVecCt
- typedef PtrMatrix_ptvector< Ctxt > helib::CtPtrMat_ptvectorCt

Functions

- void helib::packedRecrypt (const CtPtrs &cPtrs, const std::vector< zzX > &unpackConsts, const Encrypted↩ Array &ea)
- void helib::packedRecrypt (const CtPtrs &array, const std::vector< zzX > &unpackConsts, const Encrypted↩ Array &ea, long belowLvl)
- void helib::packedRecrypt (const CtPtrMat &m, const std::vector< zzX > &unpackConsts, const Encrypted↩ Array &ea, long belowLvl=LONG_MAX)
- long helib::findMinBitCapacity (const CtPtrs &v)
- long helib::findMinBitCapacity (const CtPtrMat &m)
- long helib::findMinBitCapacity (std::initializer_list< const CtPtrs * > list)
- void helib::innerProduct (Ctxt &result, const CtPtrs &v1, const CtPtrs &v2)
- Ctxt helib::innerProduct (const CtPtrs &v1, const CtPtrs &v2)

8.12.1 Detailed Description

Unified interface for vector of pointers to ciphertexts.

8.13 /HElib/include/helib/Ctxt.h File Reference

Declarations of a BGV-type ciphertext and key-switching matrices.

```
#include <cfloat>
#include <helib/DoubleCRT.h>
#include <helib/apiAttributes.h>
```

Classes

- class helib::Ptxt

  An object that mimics the functionality of the `Ctxt` object, and acts as a convenient entry point for inputting/encoding data which is to be encrypted.
- class helib::SKHandle

  A handle, describing the secret-key element that "matches" a part, of the form s^ r(X^ t).
- class helib::CtxtPart

  One entry in a ciphertext std::vector.
- class helib::Ctxt

  A Ctxt object holds a single ciphertext.

Namespaces

- helib

Functions

- std::ostream & helib::operator<< (std::ostream &s, const SKHandle &handle)
- std::istream & helib::operator>> (std::istream &s, CtxtPart &p)
- std::ostream & helib::operator<< (std::ostream &s, const CtxtPart &p)
- void helib::totalProduct (Ctxt &out, const std::vector< Ctxt > &v)
- void helib::incrementalProduct (std::vector< Ctxt > &v)
- void helib::innerProduct (Ctxt &result, const std::vector< Ctxt > &v1, const std::vector< Ctxt > &v2)
- Ctxt helib::innerProduct (const std::vector< Ctxt > &v1, const std::vector< Ctxt > &v2)
- void helib::innerProduct (Ctxt &result, const std::vector< Ctxt > &v1, const std::vector< DoubleCRT > &v2)

    Compute the inner product of a vectors of ciphertexts and a constant vector.
- Ctxt helib::innerProduct (const std::vector< Ctxt > &v1, const std::vector< DoubleCRT > &v2)
- void helib::innerProduct (Ctxt &result, const std::vector< Ctxt > &v1, const std::vector< NTL::ZZX > &v2)
- Ctxt helib::innerProduct (const std::vector< Ctxt > &v1, const std::vector< NTL::ZZX > &v2)
- void helib::CheckCtxt (const Ctxt &c, const char *label)

    print to cerr some info about ciphertext
- void helib::extractDigits (std::vector< Ctxt > &digits, const Ctxt &c, long r=0)

    Extract the mod-p digits of a mod-p^r ciphertext.
- void helib::extractDigits (std::vector< Ctxt > &digits, const Ctxt &c, long r, bool shortCut)
- void helib::extendExtractDigits (std::vector< Ctxt > &digits, const Ctxt &c, long r, long e)

8.13.1 Detailed Description

Declarations of a BGV-type ciphertext and key-switching matrices.

A ciphertext is a std::vector of "ciphertext parts", each part consists of a polynomial (element of polynomial ring R_Q) and a "handle" describing the secret-key polynomial that this part multiplies during decryption. For example:

- A "canonical" ciphertext has two parts, the first part multiplies 1 and the second multiplies the "base" secret key s.
- When you multiply two canonical ciphertexts you get a 3-part ciphertext, with parts corresponding to 1, s, and s^2.
- When you apply automorphism X->X^t to a generic ciphertext, then
    - the part corresponding to 1 still remains wrt 1
    - every other part corresponding to some s' will now be corresponding to the polynomial s'(X^t) mod Phi_m(X)

This type of representation lets you in principle add ciphertexts that are defined with respect to different keys:

- For parts of the two ciphertexts that point to the same secret-key polynomial, you just add the two Double-CRT polynomials
- Parts in one ciphertext that do not have counter-part in the other ciphertext will just be included in the result intact. For example, you have the ciphertexts C1 = (a relative to 1, b relative to s) C2 = (u relative to 1, v relative to s(X^3)) Then their sum will be C1+C2 = (a+u relative to 1, b relative to s, v relative to s(X^3))

Similarly, in principle you can also multiply arbitrary ciphertexts, even ones that are defined with respect to different keys, and the result will be defined with respect to the tensor product of the two keys.

The current implementation is more restrictive, however. It requires that a ciphertext has one part wrt 1, that for every r>=1 there is at most one part wrt to s^r(X^t) (for some t), and that the r's are consecutive. For example you cannot have parts wrt (1,s,s^3) without having a part wrt s^2.

It follows that you can only add/multiply ciphertexts if one of the two lists of handles is a prefix of the other. For example, one can add a ciphertext wrt (1,s(X^2)) to another wrt (1,s(X^2),s^2(X^2)), but not to another ciphertext wrt (1,s).

8.14 /HElib/include/helib/debugging.h File Reference

debugging utilities

```
#include <iostream>
#include <string>
#include <NTL/ZZX.h>
#include <helib/NumbTh.h>
```

Namespaces

- helib

Macros

- #define FLAG_PRINT_ZZX 1
- #define FLAG_PRINT_POLY 2
- #define FLAG_PRINT_VEC 4 /∗ decode to ZZX ∗/
- #define FLAG_PRINT_DVEC 8 /∗ decode to double float ∗/
- #define FLAG_PRINT_XVEC 16 /∗ decode to complex numbers ∗/

Functions

- void helib::setupDebugGlobals (SecKey ∗debug_key, const std::shared_ptr< const EncryptedArray > &debug_ea, NTL::ZZX debug_ptxt=NTL::ZZX{})

  Setup function for setting up the global debug variables.
- void helib::cleanupDebugGlobals ()

  Cleanup function for clearing the global debug variables.
- void helib::decryptAndPrint (std::ostream &s, const Ctxt &ctxt, const SecKey &sk, const EncryptedArray &ea, long flags=0)
- NTL::xdouble helib::embeddingLargestCoeff (const Ctxt &ctxt, const SecKey &sk)
- double helib::realToEstimatedNoise (const Ctxt &ctxt, const SecKey &sk)
- void helib::checkNoise (const Ctxt &ctxt, const SecKey &sk, const std::string &msg, double thresh=10.0)
- bool helib::decryptAndCompare (const Ctxt &ctxt, const SecKey &sk, const EncryptedArray &ea, const PlaintextArray &pa)
- void helib::rawDecrypt (NTL::ZZX &plaintxt, const std::vector< NTL::ZZX > &zzParts, const DoubleCRT &s↩ Key, long q=0)
- template< typename VEC >
  std::ostream & helib::printVec (std::ostream &s, const VEC &v, long nCoeffs=40)
- std::ostream & helib::printZZX (std::ostream &s, const NTL::ZZX &poly, long nCoeffs=40)

Variables

- SecKey ∗ helib::dbgKey = nullptr
- std::shared_ptr< const EncryptedArray > helib::dbgEa = nullptr
- NTL::ZZX helib::dbg_ptxt

8.14.1 Detailed Description

debugging utilities

8.14.2 Macro Definition Documentation

8.14.2.1 FLAG_PRINT_DVEC

```
#define FLAG_PRINT_DVEC 8 /* decode to double float */
```

8.14.2.2 FLAG_PRINT_POLY

```
#define FLAG_PRINT_POLY 2
```

8.14.2.3 FLAG_PRINT_VEC

```
#define FLAG_PRINT_VEC 4 /* decode to ZZX */
```

8.14.2.4 FLAG_PRINT_XVEC

```
#define FLAG_PRINT_XVEC 16 /* decode to complex numbers */
```

8.14.2.5 FLAG_PRINT_ZZX

```
#define FLAG_PRINT_ZZX 1
```

8.15 /HElib/include/helib/DoubleCRT.h File Reference

Integer polynomials (elements in the ring R_Q) in double-CRT form.

```
#include <helib/zzX.h>
#include <helib/NumbTh.h>
#include <helib/IndexMap.h>
#include <helib/timing.h>
```

Classes

- class helib::DoubleCRTHelper

    A helper class to enforce consistency within an DoubleCRTHelper object.
- class helib::DoubleCRT

    Implementing polynomials (elements in the ring R_Q) in double-CRT form.

Namespaces

- helib

Typedefs

- typedef std::shared_ptr< DoubleCRT > helib::DCRTptr
- typedef std::shared_ptr< NTL::ZZX > helib::ZZXptr

Functions

- void helib::conv (DoubleCRT &d, const NTL::ZZX &p)
- void helib::conv (NTL::ZZX &p, const DoubleCRT &d)
- NTL::ZZX helib::to_ZZX (const DoubleCRT &d)

8.15.1 Detailed Description

Integer polynomials (elements in the ring R_Q) in double-CRT form.

8.16 /HElib/include/helib/EncryptedArray.h File Reference

Data-movement operations on encrypted arrays of slots.

```
#include <exception>
#include <cmath>
#include <complex>
#include <NTL/Lazy.h>
#include <NTL/pair.h>
#include <NTL/SmartPtr.h>
#include <helib/DoubleCRT.h>
#include <helib/Context.h>
#include <helib/Ctxt.h>
#include <helib/keys.h>
```

Classes

- class helib::EncryptedArrayBase

  virtual class for data-movement operations on arrays of slots
- class helib::EncryptedArrayDerived< type >

  Derived concrete implementation of EncryptedArrayBase.
- class helib::EncryptedArrayCx

  A different derived class to be used for the approximate-numbers scheme.
- class helib::EncryptedArray

  A simple wrapper for a smart pointer to an EncryptedArrayBase. This is the interface that higher-level code should use.
- class helib::PlaintextArrayBase
- class helib::PlaintextArrayDerived< type >
- class helib::PlaintextArray

Namespaces

- helib

Macros

- #define HELIB_MORE_UNWRAPARGS(n) NTL_SEPARATOR_##n NTL_REPEATER_##n(NTL_UNWRAPARG)
- #define PA_BOILER
- #define CPA_BOILER

Typedefs

- typedef std::complex< double > helib::cx_double

Functions

- template<typename RX , typename RXModulus >
  void helib::plaintextAutomorph (RX &bb, const RX &a, long k, long m, const RXModulus &PhimX)
- template<typename RX , typename type >
  void helib::plaintextAutomorph (RX &b, const RX &a, long i, long j, const EncryptedArrayDerived< type > &ea)
- EncryptedArrayBase ∗ helib::buildEncryptedArray (const Context &context, const PAlgebraMod &alMod, const NTL::ZZX &G=NTL::ZZX::zero())

  A "factory" for building EncryptedArrays.
- std::ostream & helib::operator<< (std::ostream &s, const PlaintextArray &pa)
- void helib::rotate (const EncryptedArray &ea, PlaintextArray &pa, long k)
- void helib::shift (const EncryptedArray &ea, PlaintextArray &pa, long k)
- void helib::encode (const EncryptedArray &ea, PlaintextArray &pa, const std::vector< long > &array)
- void helib::encode (const EncryptedArray &ea, PlaintextArray &pa, const std::vector< NTL::ZZX > &array)
- void helib::encode (const EncryptedArray &ea, PlaintextArray &pa, long val)
- void helib::encode (const EncryptedArray &ea, PlaintextArray &pa, const NTL::ZZX &val)
- void helib::random (const EncryptedArray &ea, PlaintextArray &pa)
- void helib::decode (const EncryptedArray &ea, std::vector< long > &array, const PlaintextArray &pa)
- void helib::decode (const EncryptedArray &ea, std::vector< NTL::ZZX > &array, const PlaintextArray &pa)

- bool helib::equals (const EncryptedArray &ea, const PlaintextArray &pa, const PlaintextArray &other)
- bool helib::equals (const EncryptedArray &ea, const PlaintextArray &pa, const std::vector< long > &other)
- bool helib::equals (const EncryptedArray &ea, const PlaintextArray &pa, const std::vector< NTL::ZZX > &other)
- void helib::add (const EncryptedArray &ea, PlaintextArray &pa, const PlaintextArray &other)
- void helib::sub (const EncryptedArray &ea, PlaintextArray &pa, const PlaintextArray &other)
- void helib::mul (const EncryptedArray &ea, PlaintextArray &pa, const PlaintextArray &other)
- void helib::negate (const EncryptedArray &ea, PlaintextArray &pa)
- void helib::frobeniusAutomorph (const EncryptedArray &ea, PlaintextArray &pa, long j)
- void helib::frobeniusAutomorph (const EncryptedArray &ea, PlaintextArray &pa, const NTL::Vec< long > &vec)
- void helib::applyPerm (const EncryptedArray &ea, PlaintextArray &pa, const NTL::Vec< long > &pi)
- void helib::power (const EncryptedArray &ea, PlaintextArray &pa, long e)
- void helib::runningSums (const EncryptedArray &ea, Ctxt &ctxt)

  A ctxt that encrypts $(x_1, ..., x_n)$ *is replaced by an encryption of* $(y_1, ..., y_n)$, *where* $y_i = sum_{j \leq i} x_j$.

8.16.1 Detailed Description

Data-movement operations on encrypted arrays of slots.

8.16.2 Macro Definition Documentation

8.16.2.1 CPA_BOILER

```
#define CPA_BOILER
```

Value:

```
const PAlgebraModDerived<type>& tab = ea.getTab();                    \
UNUSED const RX& G = ea.getG();                                       \
UNUSED long n = ea.size();                                            \
UNUSED long d = ea.getDegree();                                       \
const std::vector<RX>& data = pa.getData<type>();                     \
RBak bak;                                                             \
bak.save();                                                           \
tab.restoreContext();
```

8.16.2.2 HELIB_MORE_UNWRAPARGS

```
#define HELIB_MORE_UNWRAPARGS(
                n ) NTL_SEPARATOR_##n NTL_REPEATER_##n(NTL_UNWRAPARG)
```

8.16.2.3 PA_BOILER

```
#define PA_BOILER
```

Value:
```
const PAlgebraModDerived<type>& tab = ea.getTab();                              \
UNUSED const RX& G = ea.getG();                                                 \
UNUSED long n = ea.size();                                                      \
UNUSED long d = ea.getDegree();                                                 \
std::vector<RX>& data = pa.getData<type>();                                     \
RBak bak;                                                                       \
bak.save();                                                                     \
tab.restoreContext();
```

8.17 /HElib/include/helib/EvalMap.h File Reference

Implementing the recryption linear transformations.

```
#include <helib/EncryptedArray.h>
#include <helib/matmul.h>
```

Classes

- class helib::EvalMap

    Class that provides the functionality for the linear transforms used in boostrapping. The constructor is invoked with three arguments:
- class helib::ThinEvalMap

    Class that provides the functionality for the linear transforms used in "thin" boostrapping, where slots are assumed to contain constants. The interface is exactly the same as for EvalMap, except that the constructor does not have a normal_basis parameter.

Namespaces

- helib

8.17.1 Detailed Description

Implementing the recryption linear transformations.

8.18 /HElib/include/helib/exceptions.h File Reference

Various HElib-specific exception types.

```
#include <exception>
#include <stdexcept>
#include <sstream>
```

Classes

- class helib::Exception
  Base class that other HElib exception classes inherit from.
- class helib::LogicError
  Inherits from Exception and std::logic_error.
- class helib::OutOfRangeError
  Inherits from Exception and std::out_of_range.
- class helib::RuntimeError
  Inherits from Exception and std::runtime_error.
- class helib::InvalidArgument
  Inherits from Exception and std::invalid_argument.

Namespaces

- helib

8.18.1 Detailed Description

Various HElib-specific exception types.

This is largely a mirror image of the standard library exceptions, with the added ancestor of `Exception`. This allows one to distinguish between general exceptions and those specifically thrown by HElib. For example:

```
try {
  // Some code including calls to HElib
}
catch(const Exception& err) {
  // HElib error handling
}
catch(const std::exception& err) {
  // Generic error handling
}
```

To make sure that this is a pattern that can be used, we should only throw exceptions derived from `Exception` wherever possible.

8.19 /HElib/include/helib/FHE.h File Reference

Deprecated entry point header for HElib (legacy alias of helib.h)

```
#include <helib/helib.h>
```

8.19.1 Detailed Description

Deprecated entry point header for HElib (legacy alias of helib.h)

8.20 /HElib/include/helib/fhe_stats.h File Reference

```
#include <vector>
#include <iostream>
```

Classes

- struct helib::fhe_stats_record

Namespaces

- helib

Macros

- #define HELIB_STATS_UPDATE(name, val)
- #define HELIB_STATS_SAVE(name, val)

Functions

- void helib::print_stats (std::ostream &s)
- const std::vector< double > * helib::fetch_saved_values (const char *)

Variables

- bool helib::fhe_stats = false

8.20.1 Macro Definition Documentation

8.20.1.1 HELIB_STATS_SAVE

```
#define HELIB_STATS_SAVE(
                name,
                val )
```

Value:

```
do {                                                                  \
  if (fhe_stats) {                                                    \
    static fhe_stats_record _local_stats_record(name);                \
    _local_stats_record.save(val);                                    \
  }                                                                   \
} while (0)
```

8.20.1.2 HELIB_STATS_UPDATE

```
#define HELIB_STATS_UPDATE(
                name,
                val )
```

Value:

```
do {                                                                  \
  if (fhe_stats) {                                                    \
    static fhe_stats_record _local_stats_record(name);                \
    _local_stats_record.update(val);                                  \
  }                                                                   \
} while (0)
```

8.21 /HElib/include/helib/helib.h File Reference

Entry point header for HElib.

```
#include <helib/DoubleCRT.h>
#include <helib/Context.h>
#include <helib/Ctxt.h>
#include <helib/keySwitching.h>
#include <helib/keys.h>
#include <helib/EncryptedArray.h>
#include <helib/Ptxt.h>
```

8.21.1 Detailed Description

Entry point header for HElib.

8.22 /HElib/include/helib/hypercube.h File Reference

Hypercubes and their slices.

```
#include <helib/NumbTh.h>
```

Classes

- class helib::CubeSignature

  Holds a vector of dimensions for a hypercube and some additional data.
- class helib::HyperCube< T >

  A multi-dimensional cube.
- class helib::ConstCubeSlice< T >

  A constant lower-dimension slice of a hypercube.
- class helib::CubeSlice< T >

  A lower-dimension slice of a hypercube.

Namespaces

- helib

Functions

- std::ostream & helib::operator<< (std::ostream &s, const CubeSignature &sig)
- template<typename T >
  void helib::getHyperColumn (NTL::Vec< T > &v, const ConstCubeSlice< T > &s, long pos)
- template<typename T >
  void helib::setHyperColumn (const NTL::Vec< T > &v, const CubeSlice< T > &s, long pos)
- template<typename T >
  void helib::setHyperColumn (const NTL::Vec< T > &v, const CubeSlice< T > &s, long pos, const T &val)
- template<typename T >
  void helib::print3D (const HyperCube< T > &c)

8.22.1 Detailed Description

Hypercubes and their slices.

8.23 /HElib/include/helib/IndexMap.h File Reference

Implementation of a map indexed by a dynamic set of integers.

```
#include <helib/IndexSet.h>
#include <helib/clonedPtr.h>
```

Classes

- class helib::IndexMapInit< T >

  Initializing elements in an IndexMap.
- class helib::IndexMap< T >

  IndexMap<T> implements a generic map indexed by a dynamic index set.

Namespaces

- helib

Functions

- template<typename T >
  bool helib::operator== (const IndexMap< T > &map1, const IndexMap< T > &map2)

  Comparing maps, by comparing all the elements.
- template<typename T >
  bool helib::operator!= (const IndexMap< T > &map1, const IndexMap< T > &map2)

8.23.1 Detailed Description

Implementation of a map indexed by a dynamic set of integers.

8.24 /HElib/include/helib/IndexSet.h File Reference

A dynamic set of integers.

```
#include <helib/NumbTh.h>
```

Classes

- class helib::IndexSet

    A dynamic set of non-negative integers.
- class helib::IndexSet::iterator

Namespaces

- helib

Functions

- IndexSet helib::operator| (const IndexSet &s, const IndexSet &t)

    union
- IndexSet helib::operator& (const IndexSet &s, const IndexSet &t)

    intersection
- IndexSet helib::operator^ (const IndexSet &s, const IndexSet &t)

    exclusive-or
- IndexSet helib::operator/ (const IndexSet &s, const IndexSet &t)

    set minus
- std::ostream & helib::operator<< (std::ostream &str, const IndexSet &set)
- std::istream & helib::operator>> (std::istream &str, IndexSet &set)
- long helib::card (const IndexSet &s)

    Functional cardinality.
- bool helib::empty (const IndexSet &s)
- bool helib::operator<= (const IndexSet &s1, const IndexSet &s2)

    Is s1 subset or equal to s2.
- bool helib::operator< (const IndexSet &s1, const IndexSet &s2)

    Is s1 strict subset of s2.
- bool helib::operator>= (const IndexSet &s1, const IndexSet &s2)

    Is s2 subset or equal to s2.
- bool helib::operator> (const IndexSet &s1, const IndexSet &s2)

    Is s2 strict subset of s1.
- bool helib::disjoint (const IndexSet &s1, const IndexSet &s2)

    Functional disjoint.

8.24.1 Detailed Description

A dynamic set of integers.

8.25 /HElib/include/helib/intraSlot.h File Reference

Packing/unpacking of mod-p integers in GF(p^d) slots.

```
#include <NTL/BasicThreadPool.h>
#include <helib/Context.h>
#include <helib/EncryptedArray.h>
#include <helib/Ctxt.h>
#include <helib/CtPtrs.h>
```

Namespaces

- helib

Functions

- void helib::buildUnpackSlotEncoding (std::vector< zzX > &unpackSlotEncoding, const EncryptedArray &ea)
- void helib::unpack (const CtPtrs &unpacked, const Ctxt &packed, const EncryptedArray &ea, const std::vector< zzX > &unpackSlotEncoding)
- long helib::unpack (const CtPtrs &unpacked, const CtPtrs &packed, const EncryptedArray &ea, const std::vector< zzX > &unpackSlotEncoding)
- void helib::repack (Ctxt &packed, const CtPtrs &unpacked, const EncryptedArray &ea)
- long helib::repack (const CtPtrs &packed, const CtPtrs &unpacked, const EncryptedArray &ea)
- void helib::unpackSlots (std::vector< unsigned long > &value, PlaintextArray &pa, const EncryptedArray &ea)
- void helib::unpackSlots (std::vector< unsigned long > &value, NTL::ZZX &pa, const EncryptedArray &ea)
- void helib::packConstant (zzX &result, unsigned long data, long nbits, const EncryptedArray &ea)
- void helib::packConstants (zzX &result, const std::vector< unsigned long > &data, long nbits, const EncryptedArray &ea)

8.25.1 Detailed Description

Packing/unpacking of mod-p integers in GF(p^d) slots.

8.26 /HElib/include/helib/keys.h File Reference

- Declaration of public key

```
#include <helib/keySwitching.h>
```

Classes

- class helib::PubKey
  The public key.
- class helib::SecKey
  The secret key.

Namespaces

- helib

Macros

- #define HELIB_KSS_UNKNOWN (0)
- #define HELIB_KSS_FULL (1)
- #define HELIB_KSS_BSGS (2)
- #define HELIB_KSS_MIN (3)

Functions

- void helib::writePubKeyBinary (std::ostream &str, const PubKey &pk)
- void helib::readPubKeyBinary (std::istream &str, PubKey &pk)
- void helib::writeSecKeyBinary (std::ostream &str, const SecKey &sk)
- void helib::readSecKeyBinary (std::istream &str, SecKey &sk)
- double helib::RLWE (DoubleCRT &c0, DoubleCRT &c1, const DoubleCRT &s, long p, NTL::ZZ ∗prg←
Seed=nullptr)
- double helib::RLWE1 (DoubleCRT &c0, const DoubleCRT &c1, const DoubleCRT &s, long p)

    Same as RLWE, but assumes that c1 is already chosen by the caller.

8.26.1 Detailed Description

- Declaration of public key

- Declaration of secret key

8.26.2 Macro Definition Documentation

8.26.2.1 HELIB_KSS_BSGS

```
#define HELIB_KSS_BSGS (2)
```

8.26.2.2 HELIB_KSS_FULL

```
#define HELIB_KSS_FULL (1)
```

8.26.2.3 HELIB_KSS_MIN

```
#define HELIB_KSS_MIN (3)
```

8.26.2.4 HELIB_KSS_UNKNOWN

```
#define HELIB_KSS_UNKNOWN (0)
```

8.27 /HElib/include/helib/keySwitching.h File Reference

- Declaration of key switching matrices

```
#include <climits>
#include <helib/DoubleCRT.h>
#include <helib/Context.h>
#include <helib/Ctxt.h>
```

Classes

- class helib::KeySwitch
  Key-switching matrices.

Namespaces

- helib

Functions

- std::ostream & helib::operator<< (std::ostream &str, const KeySwitch &matrix)

Strategies for generating key-switching matrices

These functions are implemented in KeySwitching.cpp

- #define HELIB_KEYSWITCH_THRESH (50)
  Constant defining threshold above which a baby-set/giant-step strategy is used.
- #define HELIB_KEYSWITCH_MIN_THRESH (8)
  Constant defining threshold above which a single giant step matrix is added even in HELIB_KSS_MIN mode. This helps in the matmul routines.
- long helib::KSGiantStepSize (long D)
  Function that returns number of baby steps. Used to keep this and matmul routines "in sync".
- void helib::addAllMatrices (SecKey &sKey, long keyID=0)
  Maximalistic approach: generate matrices s(X^e)->s(X) for all e in Zm.*
- void helib::addFewMatrices (SecKey &sKey, long keyID=0)
  Generate matrices so every s(X^e) can be reLinearized in at most two steps.
- void helib::addSome1DMatrices (SecKey &sKey, long bound=HELIB_KEYSWITCH_THRESH, long keyID=0)
  *Generate some matrices of the form s(X^{g^i})->s(X), but not all. For a generator g whose order is larger than bound, generate only enough matrices for the giant-step/baby-step procedures (2*sqrt(ord(g))of them).*
- void helib::add1DMatrices (SecKey &sKey, long keyID=0)
  Generate all matrices s(X^{g^i})->s(X) for generators g of Zm /(p) and i<ord(g). If g has different orders in Zm* and Zm* /(p) then generate also matrices of the form s(X^{g^{-i}})->s(X)*
- void helib::addBSGS1DMatrices (SecKey &sKey, long keyID=0)
- void helib::addSomeFrbMatrices (SecKey &sKey, long bound=HELIB_KEYSWITCH_THRESH, long keyID=0)
  Generate all/some Frobenius matrices of the form s(X^{p^i})->s(X)
- void helib::addFrbMatrices (SecKey &sKey, long keyID=0)
- void helib::addBSGSFrbMatrices (SecKey &sKey, long keyID=0)
- void helib::addMinimal1DMatrices (SecKey &sKey, long keyID=0)
  These routines just add a single matrix (or two, for bad dimensions)
- void helib::addMinimalFrbMatrices (SecKey &sKey, long keyID=0)
- void helib::addMatrices4Network (SecKey &sKey, const PermNetwork &net, long keyID=0)
- void helib::addTheseMatrices (SecKey &sKey, const std::set< long > &automVals, long keyID=0)
  Generate specific key-switching matrices, described by the given set.

8.27.1 Detailed Description

- Declaration of key switching matrices
- Other key switching-related free functions

8.27.2 Macro Definition Documentation

8.27.2.1 HELIB_KEYSWITCH_MIN_THRESH

```
#define HELIB_KEYSWITCH_MIN_THRESH (8)
```

Constant defining threshold above which a single giant step matrix is added even in HELIB_KSS_MIN mode. This helps in the matmul routines.

8.27.2.2 HELIB_KEYSWITCH_THRESH

```
#define HELIB_KEYSWITCH_THRESH (50)
```

Constant defining threshold above which a baby-set/giant-step strategy is used.

8.28 /HElib/include/helib/matching.h File Reference

Classes and functions for max-flow in a generic graph.

```
#include <helib/NumbTh.h>
```

Classes

- class helib::FlowEdge

  An edge in a flow graph.
- class helib::LabeledEdge

  A generic directed edge in a graph with some labels.
- class helib::LabeledVertex

  A generic node in a graph with some labels.
- class helib::BipartitleGraph

  A bipartite flow graph.

Namespaces

- helib

Typedefs

- typedef std::unordered_map< long, FlowEdge > helib::FNeighborList
- typedef std::vector< FNeighborList > helib::FlowGraph
- typedef std::unordered_multimap< long, LabeledEdge > helib::LNeighborList

Functions

- long helib::maximum_flow (FlowGraph &fg, long src, long sink)

8.28.1 Detailed Description

Classes and functions for max-flow in a generic graph.

8.29 /HElib/include/helib/matmul.h File Reference

some matrix / linear algenra stuff

```
#include <helib/EncryptedArray.h>
```

Classes

- class helib::MatMulFull
- class helib::MatMulFull_derived< type >
- class helib::BlockMatMulFull
- class helib::BlockMatMulFull_derived< type >
- class helib::MatMul1D
- class helib::MatMul1D_partial< type >
- class helib::MatMul1D_derived< type >
- class helib::BlockMatMul1D
- class helib::BlockMatMul1D_partial< type >
- class helib::BlockMatMul1D_derived< type >
- struct helib::ConstMultiplierCache
- class helib::MatMulExecBase
- class helib::MatMul1DExec
- class helib::BlockMatMul1DExec
- class helib::MatMulFullExec
- class helib::BlockMatMulFullExec

Namespaces

- helib

Functions

- void helib::traceMap (Ctxt &ctxt)
- void helib::mul (PlaintextArray &pa, const MatMul1D &mat)
- void helib::mul (PlaintextArray &pa, const BlockMatMul1D &mat)
- void helib::mul (PlaintextArray &pa, const MatMulFull &mat)
- void helib::mul (PlaintextArray &pa, const BlockMatMulFull &mat)

Variables

- int helib::fhe_test_force_bsgs = 0
- int helib::fhe_test_force_hoist = 0

8.29.1 Detailed Description

some matrix / linear algenra stuff

8.30 /HElib/include/helib/multicore.h File Reference

Support for multi-threaded implementations.

Namespaces

- helib

Macros

- #define HELIB_atomic_long long
- #define HELIB_atomic_ulong unsigned long
- #define HELIB_MUTEX_TYPE int
- #define HELIB_MUTEX_GUARD(mx) ((void)mx)

8.30.1 Detailed Description

Support for multi-threaded implementations.

8.30.2 Macro Definition Documentation

8.30.2.1 HELIB_atomic_long

```
#define HELIB_atomic_long long
```

8.30.2.2 HELIB_atomic_ulong

```
#define HELIB_atomic_ulong unsigned long
```

8.30.2.3 HELIB_MUTEX_GUARD

```
#define HELIB_MUTEX_GUARD(
              mx ) ((void)mx)
```

8.30.2.4 HELIB_MUTEX_TYPE

```
#define HELIB_MUTEX_TYPE int
```

8.31 /HElib/include/helib/norms.h File Reference

```
#include <vector>
#include <complex>
#include <NTL/ZZX.h>
#include <NTL/xdouble.h>
#include <helib/zzX.h>
```

Namespaces

- helib

Functions

- long helib::sumOfCoeffs (const zzX &f)
- NTL::ZZ helib::sumOfCoeffs (const NTL::ZZX &f)
- NTL::ZZ helib::sumOfCoeffs (const DoubleCRT &f)
- template< typename T >
  double helib::largestCoeff (const NTL::Vec< T > &f)

  The L-infinity norm of an element (in coefficient representation)
- template< typename T >
  double helib::largestCoeff (const std::vector< T > &f)
- NTL::ZZ helib::largestCoeff (const NTL::ZZX &f)
- NTL::ZZ helib::largestCoeff (const NTL::Vec< NTL::ZZ > &f)
- NTL::ZZ helib::largestCoeff (const DoubleCRT &f)
- double helib::coeffsL2NormSquared (const zzX &f)

  The L2-norm of an element (in coefficient representation)
- NTL::xdouble helib::coeffsL2NormSquared (const NTL::ZZX &f)
- NTL::xdouble helib::coeffsL2NormSquared (const DoubleCRT &f)
- double helib::coeffsL2Norm (const zzX &f)

- NTL::xdouble helib::coeffsL2Norm (const NTL::ZZX &f)
- NTL::xdouble helib::coeffsL2Norm (const DoubleCRT &f)
- double helib::embeddingLargestCoeff (const zzX &f, const PAlgebra &palg)
- double helib::embeddingLargestCoeff (const std::vector< double > &f, const PAlgebra &palg)
- void helib::embeddingLargestCoeff_x2 (double &norm1, double &norm2, const std::vector< double > &f1, const std::vector< double > &f2, const PAlgebra &palg)
- NTL::xdouble helib::embeddingLargestCoeff (const NTL::ZZX &f, const PAlgebra &palg)
- void helib::CKKS_canonicalEmbedding (std::vector< cx_double > &v, const zzX &f, const PAlgebra &palg)
- void helib::CKKS_canonicalEmbedding (std::vector< cx_double > &v, const NTL::ZZX &f, const PAlgebra &palg)
- void helib::CKKS_canonicalEmbedding (std::vector< cx_double > &v, const std::vector< double > &f, const PAlgebra &palg)
- void helib::CKKS_embedInSlots (zzX &f, const std::vector< cx_double > &v, const PAlgebra &palg, double scaling)

8.31.1 Detailed Description

- computing various norms of ring elements

8.32 /HElib/include/helib/NumbTh.h File Reference

Miscellaneous utility functions.

```
#include <vector>
#include <set>
#include <cmath>
#include <complex>
#include <string>
#include <climits>
#include <iostream>
#include <fstream>
#include <istream>
#include <sstream>
#include <ctime>
#include <memory>
#include <unordered_map>
#include <NTL/version.h>
#include <NTL/ZZ.h>
#include <NTL/ZZX.h>
#include <NTL/ZZ_p.h>
#include <NTL/ZZ_pX.h>
#include <NTL/xdouble.h>
#include <NTL/mat_GF2.h>
#include <NTL/mat_GF2E.h>
#include <NTL/GF2XFactoring.h>
#include <NTL/mat_lzz_p.h>
#include <NTL/mat_lzz_pE.h>
#include <NTL/lzz_pXFactoring.h>
#include <NTL/GF2EX.h>
#include <NTL/lzz_pEX.h>
#include <NTL/FFT.h>
#include <helib/range.h>
#include <helib/assertions.h>
#include <helib/apiAttributes.h>
```

Classes

- class helib::RandomState

  Facility for "restoring" the NTL PRG state.
- class helib::zz_pXModulus1

  Auxiliary classes to facilitate faster reduction mod Phi_m(X) when the input has degree less than m.
- class helib::ZZ_pXModulus1

  placeholder for pXModulus ...no optimizations

Namespaces

- helib
- helib::FHEglobals

Macros

- #define ERFC_INVERSE_SIZE (long(sizeof(erfc_inverse) / sizeof(erfc_inverse[0])))

Typedefs

- typedef long helib::LONG

Functions

- bool helib::setDryRun (bool toWhat=true)
- bool helib::isDryRun ()
- void helib::setAutomorphVals (std::set< long > *aVals)
- bool helib::isSetAutomorphVals ()
- void helib::recordAutomorphVal (long k)
- void helib::setAutomorphVals2 (std::set< long > *aVals)
- bool helib::isSetAutomorphVals2 ()
- void helib::recordAutomorphVal2 (long k)
- long helib::bitSetToLong (long bits, long bitSize)

  Considers `bits` as a vector of bits and returns the value it represents when interpreted as a n-bit 2's complement number, where n is given by `bitSize`.
- long helib::mcMod (long a, long b)

  Routines for computing mathematically correct mod and div.
- long helib::mcDiv (long a, long b)
- long helib::balRem (long a, long q)
- double helib::fsquare (double x)

  Return the square of a number as a double.
- long helib::multOrd (long p, long m)

  Return multiplicative order of p modulo m, or 0 if GCD(p, m) != 1.
- void helib::ppsolve (NTL::vec_zz_pE &x, const NTL::mat_zz_pE &A, const NTL::vec_zz_pE &b, long p, long r)

  Prime power solver.
- void helib::ppsolve (NTL::vec_GF2E &x, const NTL::mat_GF2E &A, const NTL::vec_GF2E &b, long p, long r)

  A version for GF2: must have p == 2 and r == 1.
- void helib::ppInvert (NTL::mat_zz_p &X, const NTL::mat_zz_p &A, long p, long r)

Compute the inverse mod p^r of an n x n matrix.

- void helib::ppInvert (NTL::mat_zz_pE &X, const NTL::mat_zz_pE &A, long p, long r)
- void helib::ppInvert (NTL::mat_GF2 &X, const NTL::mat_GF2 &A, UNUSED long p, UNUSED long r)
- void helib::ppInvert (NTL::mat_GF2E &X, const NTL::mat_GF2E &A, UNUSED long p, UNUSED long r)
- void helib::buildLinPolyMatrix (NTL::mat_zz_pE &M, long p)
- void helib::buildLinPolyMatrix (NTL::mat_GF2E &M, long p)
- void helib::buildLinPolyCoeffs (NTL::vec_zz_pE &C, const NTL::vec_zz_pE &L, long p, long r)

  Combination of buildLinPolyMatrix and ppsolve.
- void helib::buildLinPolyCoeffs (NTL::vec_GF2E &C, const NTL::vec_GF2E &L, long p, long r)

  A version for GF2: must be called with p == 2 and r == 1.
- void helib::applyLinPoly (NTL::zz_pE &beta, const NTL::vec_zz_pE &C, const NTL::zz_pE &alpha, long p)

  Apply a linearized polynomial with coefficient vector C.
- void helib::applyLinPoly (NTL::GF2E &beta, const NTL::vec_GF2E &C, const NTL::GF2E &alpha, long p)

  A version for GF2: must be called with p == 2 and r == 1.
- double helib::log2 (const NTL::xdouble &x)

  Base-2 logarithm.
- void helib::factorize (std::vector< long > &factors, long N)

  Factoring by trial division, only works for N<2^{60}, only the primes are recorded, not their multiplicity.
- void helib::factorize (std::vector< NTL::ZZ > &factors, const NTL::ZZ &N)
- void helib::factorize (NTL::Vec< NTL::Pair< long, long >> &factors, long N)

  Factoring by trial division, only works for N<2^{60} primes and multiplicities are recorded.
- void helib::pp_factorize (std::vector< long > &factors, long N)

  Prime-power factorization.
- void helib::phiN (long &phiN, std::vector< long > &facts, long N)

  Compute Phi(N) and also factorize N.
- void helib::phiN (NTL::ZZ &phiN, std::vector< NTL::ZZ > &facts, const NTL::ZZ &N)
- long helib::phi_N (long N)

  Compute Phi(N).
- long helib::findGenerators (std::vector< long > &gens, std::vector< long > &ords, long m, long p, const std::vector< long > &candidates=std::vector< long >())
- void helib::FindPrimitiveRoot (NTL::zz_p &r, unsigned long e)

  Find e-th root of unity modulo the current modulus.
- void helib::FindPrimitiveRoot (NTL::ZZ_p &r, unsigned long e)
- long helib::mobius (long n)

  Compute mobius function (naive method as n is small).
- NTL::ZZX helib::Cyclotomic (long N)

  Compute cyclotomic polynomial.
- NTL::ZZX helib::makeIrredPoly (long p, long d)

  Return a degree-d irreducible polynomial mod p.
- long helib::primroot (long N, long phiN)

  Find a primitive root modulo N.
- long helib::ord (long N, long p)

  Compute the highest power of p that divides N.
- bool helib::is2power (long m)
- NTL::ZZX helib::RandPoly (long n, const NTL::ZZ &p)
- void helib::MulMod (NTL::ZZX &out, const NTL::ZZX &f, long a, long q, bool abs)
- void helib::MulMod (NTL::ZZX &out, const NTL::ZZX &f, long a, long q)
- NTL::ZZX helib::MulMod (const NTL::ZZX &f, long a, long q, bool abs)
- NTL::ZZX helib::MulMod (const NTL::ZZX &f, long a, long q)
- void helib::balanced_MulMod (NTL::ZZX &out, const NTL::ZZX &f, long a, long q)
- template< typename T1 , typename T2 >
  void helib::convert (T1 &x1, const T2 &x2)

A generic template that resolves to NTL's conv routine.

- template<typename T1 , typename T2 >
  void helib::convert (std::vector< T1 > &v1, const std::vector< T2 > &v2)

  generic vector conversion routines
- template<typename T1 , typename T2 >
  void helib::convert (std::vector< T1 > &v1, const NTL::Vec< T2 > &v2)
- template<typename T1 , typename T2 >
  void helib::convert (NTL::Vec< T1 > &v1, const std::vector< T2 > &v2)
- template<typename T >
  void helib::convert (std::vector< T > &v1, const std::vector< T > &v2)

  Trivial type conversion, useful for generic code.
- template<typename T1 , typename T2 >
  T1 helib::convert (const T2 &v2)
- template<typename T >
  std::vector< T > helib::vector_replicate (const T &a, long n)
- template<typename T >
  std::vector< T > helib::Vec_replicate (const T &a, long n)
- long helib::computeProd (const NTL::Vec< long > &vec)

  returns \prod_d vec[d]
- long helib::computeProd (const std::vector< long > &vec)
- void helib::mul (std::vector< NTL::ZZX > &x, const std::vector< NTL::ZZX > &a, long b)
- void helib::div (std::vector< NTL::ZZX > &x, const std::vector< NTL::ZZX > &a, long b)
- void helib::add (std::vector< NTL::ZZX > &x, const std::vector< NTL::ZZX > &a, const std::vector< NTL↩ ::ZZX > &b)
- long helib::is_in (long x, int ∗X, long sz)

  Finds whether x is an element of the set X of size sz, Returns -1 it not and the location if true.
- long helib::CRTcoeff (long p, long q, bool symmetric=false)

  Returns a CRT coefficient: x = (0 mod p, 1 mod q). If symmetric is set then x \in [-pq/2, pq/2), else x \in [0,pq)
- template<class zzvec >
  bool helib::intVecCRT (NTL::vec_ZZ &vp, const NTL::ZZ &p, const zzvec &vq, long q)

  Incremental integer CRT for vectors.
- template<typename T , bool maxFlag>
  long helib::argminmax (std::vector< T > &v)

  Find the index of the (first) largest/smallest element.
- template<typename T >
  long helib::argmax (std::vector< T > &v)
- template<typename T >
  long helib::argmin (std::vector< T > &v)
- long helib::argmax (std::vector< long > &v, bool(∗moreThan)(long, long))

  A variant with a specialized comparison function (∗moreThan)(a,b) returns the comparison a>b.
- bool helib::closeToOne (const NTL::xdouble &x, long p)
- std::pair< long, long > helib::rationalApprox (double x, long denomBound=0)
- std::pair< NTL::ZZ, NTL::ZZ > helib::rationalApprox (NTL::xdouble x, NTL::xdouble denomBound=NTL↩ ::xdouble(0.0))
- void helib::seekPastChar (std::istream &str, int cc)

  Advance the input stream beyond white spaces and a single instance of the char cc.
- template<typename T >
  void helib::reverse (NTL::Vec< T > &v, long lo, long hi)

  Reverse a vector in place.
- template<typename T >
  void helib::rotate (NTL::Vec< T > &v, long k)

  Rotate a vector in place using swaps.
- template<typename T >
  long helib::lsize (const std::vector< T > &v)

Size of STL vector as a long (rather than unsigned long)

- template< typename T >
void helib::killVec (std::vector< T > &vec)

  NTL/std compatibility.

- template< typename T >
void helib::killVec (NTL::Vec< T > &vec)
- template< typename T >
void helib::setLengthZero (std::vector< T > &vec)
- template< typename T >
void helib::setLengthZero (NTL::Vec< T > &vec)
- template< typename T >
long helib::lsize (const NTL::Vec< T > &v)
- template< typename T >
void helib::resize (NTL::Vec< T > &v, long sz, const T &val)
- template< typename T >
void helib::resize (std::vector< T > &v, long sz, const T &val)
- template< typename T >
void helib::resize (NTL::Vec< T > &v, long sz)
- template< typename T >
void helib::resize (std::vector< T > &v, long sz)
- template< typename T1 , typename T2 >
bool helib::sameObject (const T1 ∗p1, const T2 ∗p2)

  Testing if two vectors point to the same object.

- void helib::ModComp (NTL::ZZX &res, const NTL::ZZX &g, const NTL::ZZX &h, const NTL::ZZX &f)

  Modular composition of polynomials: res = g(h) mod f.

- long helib::polyEvalMod (const NTL::ZZX &poly, long x, long p)

  Evaluates a modular integer polynomial, returns poly(x) mod p.

- void helib::interpolateMod (NTL::ZZX &poly, const NTL::vec_long &x, const NTL::vec_long &y, long p, long e=1)

  Interpolate polynomial such that poly(x[i] mod p)=y[i] (mod p^ e) It is assumed that the points x[i] are all distinct modulo p.

- long helib::divc (long a, long b)

  returns ceiling(a/b); assumes a >=0, b>0, a+b <= MAX_LONG

- void helib::rem (NTL::zz_pX &r, const NTL::zz_pX &a, const zz_pXModulus1 &ff)
- template< typename T >
std::ostream & helib::operator<< (std::ostream &s, std::vector< T > v)
- template< typename T >
std::istream & helib::operator>> (std::istream &s, std::vector< T > &v)
- template< typename T >
std::string helib::vecToStr (const std::vector< T > &v)
- template< typename T >
NTL::Vec< T > helib::atoVec (const char ∗a)
- template< typename T >
std::vector< T > helib::atovector (const char ∗a)
- void helib::TofftRep_trunc (NTL::fftRep &y, const NTL::zz_pX &x, long k, UNUSED long len, long lo, long hi)
- void helib::TofftRep_trunc (NTL::fftRep &y, const NTL::zz_pX &x, long k, long len)
- template< typename T , typename P , typename... Args>
void helib::make_lazy (const NTL::Lazy< T, P > &obj, Args &&... args)
- template< typename T , typename P , typename F , typename... Args>
void helib::make_lazy_with_fun (const NTL::Lazy< T, P > &obj, F f, Args &&... args)
- void helib::Warning (const char ∗msg)
- void helib::Warning (const std::string &msg)

Variables

- const long double helib::PI
- bool helib::FHEglobals::dryRun = false

    A dry-run flag The dry-run option disables most operations, to save time. This lets us quickly go over the evaluation of a circuit and estimate the resulting noise magnitude, without having to actually compute anything.
- std::set< long > ∗ helib::FHEglobals::automorphVals = nullptr

    A list of required automorphisms When non-nullptr, causes Ctxt::smartAutomorphism to just record the requested automorphism rather than actually performing it. This can be used to get a list of needed automorphisms for certain operations and then generate all these key-switching matrices. Should only be used in conjunction with dryRun=true.
- std::set< long > ∗ helib::FHEglobals::automorphVals2 = nullptr
- const double helib::erfc_inverse [ ]

- void helib::PolyRed (NTL::ZZX &out, const NTL::ZZX &in, long q, bool abs=false)

    Reduce all the coefficients of a polynomial modulo q.
- void helib::PolyRed (NTL::ZZX &out, const NTL::ZZX &in, const NTL::ZZ &q, bool abs=false)
- void helib::PolyRed (NTL::ZZX &F, long q, bool abs=false)
- void helib::PolyRed (NTL::ZZX &F, const NTL::ZZ &q, bool abs=false)
- void helib::vecRed (NTL::Vec< NTL::ZZ > &out, const NTL::Vec< NTL::ZZ > &in, long q, bool abs)
- void helib::vecRed (NTL::Vec< NTL::ZZ > &out, const NTL::Vec< NTL::ZZ > &in, const NTL::ZZ &q, bool abs)

Some enhanced conversion routines

- void helib::convert (long &x1, const NTL::GF2X &x2)
- void helib::convert (long &x1, const NTL::zz_pX &x2)
- void helib::convert (NTL::vec_zz_pE &X, const std::vector< NTL::ZZX > &A)
- void helib::convert (NTL::mat_zz_pE &X, const std::vector< std::vector< NTL::ZZX >> &A)
- void helib::convert (std::vector< NTL::ZZX > &X, const NTL::vec_zz_pE &A)
- void helib::convert (std::vector< std::vector< NTL::ZZX >> &X, const NTL::mat_zz_pE &A)
- void helib::convert (NTL::Vec< long > &out, const NTL::ZZX &in)
- void helib::convert (NTL::Vec< long > &out, const NTL::zz_pX &in, bool symmetric=true)
- void helib::convert (NTL::Vec< long > &out, const NTL::GF2X &in)
- void helib::convert (NTL::ZZX &out, const NTL::Vec< long > &in)
- void helib::convert (NTL::GF2X &out, const NTL::Vec< long > &in)

8.32.1 Detailed Description

Miscellaneous utility functions.

8.32.2 Macro Definition Documentation

8.32.2.1 ERFC_INVERSE_SIZE

```
#define ERFC_INVERSE_SIZE (long(sizeof(erfc_inverse) / sizeof(erfc_inverse[0])))
```

8.33 /HElib/include/helib/PAlgebra.h File Reference

Declarations of the classes PAlgebra.

```
#include <exception>
#include <utility>
#include <vector>
#include <complex>
#include <helib/NumbTh.h>
#include <helib/zzX.h>
#include <helib/hypercube.h>
#include <helib/PGFFT.h>
#include <helib/clonedPtr.h>
#include <helib/apiAttributes.h>
```

Classes

- struct helib::half_FFT
- struct helib::quarter_FFT
- class helib::PAlgebra

    The structure of (Z/mZ)$*$ /(p)
- class helib::PAlgebraModBase

    Virtual base class for PAlgebraMod.
- class helib::PAlgebraModDerived< type >

    A concrete instantiation of the virtual class.
- class helib::MappingData< type >

    Auxiliary structure to support encoding/decoding slots.
- class helib::PAlgebraModDerived< type >

    A concrete instantiation of the virtual class.
- class helib::PAlgebraModCx
- class helib::PAlgebraMod

    The structure of Z[X]/(Phi_m(X), p)

Namespaces

- helib

Macros

- #define PA_INJECT(typ)

Enumerations

- enum helib::PA_tag { helib::PA_GF2_tag, helib::PA_zz_p_tag, helib::PA_cx_tag }

Functions

- PAlgebraModBase ∗ helib::buildPAlgebraMod (const PAlgebra &zMStar, long r)

    Builds a table, of type PA_GF2 if p == 2 and r == 1, and PA_zz_p otherwise.
- bool helib::comparePAlgebra (const PAlgebra &palg, unsigned long m, unsigned long p, unsigned long r, const std::vector< long > &gens, const std::vector< long > &ords)

    returns true if the palg parameters match the rest, false otherwise
- double helib::calcPolyNormBnd (long m)

8.33.1 Detailed Description

Declarations of the classes PAlgebra.

8.33.2 Macro Definition Documentation

8.33.2.1 PA_INJECT

```
#define PA_INJECT(
               typ )
```

Value:
```
static const PA_tag tag = typ::tag;                                         \
typedef typename typ::R R;                                                  \
typedef typename typ::RX RX;                                                \
typedef typename typ::vec_RX vec_RX;                                        \
typedef typename typ::RXModulus RXModulus;                                  \
typedef typename typ::RBak RBak;                                            \
typedef typename typ::RContext RContext;                                    \
typedef typename typ::RE RE;                                                \
typedef typename typ::vec_RE vec_RE;                                        \
typedef typename typ::mat_RE mat_RE;                                        \
typedef typename typ::REX REX;                                              \
typedef typename typ::REBak REBak;                                          \
typedef typename typ::vec_REX vec_REX;                                      \
typedef typename typ::REContext REContext;                                  \
typedef typename typ::mat_R mat_R;                                          \
typedef typename typ::vec_R vec_R;
```

8.34 /HElib/include/helib/permutations.h File Reference

Permutations over Hypercubes and their slices.

```
#include <helib/PAlgebra.h>
#include <helib/matching.h>
#include <helib/hypercube.h>
#include <helib/apiAttributes.h>
```

Classes

- class helib::ColPerm
  Permuting a single dimension (column) of a hypercube.
- class helib::GeneralBenesNetwork
  Implementation of generalized Benes Permutation Network.
- class helib::FullBinaryTree
  A simple implementation of full binary trees (each non-leaf has 2 children)
- class helib::TreeNode< T >
  A node in a full binary tree.
- class helib::FullBinaryTree
  A simple implementation of full binary trees (each non-leaf has 2 children)
- class helib::GenDescriptor
  A minimal description of a generator for the purpose of building tree.
- class helib::SubDimension
  A node in a tree relative to some generator.
- class helib::GeneratorTrees
  A std::vector of generator trees, one per generator in Zm∗/(p)
- class helib::PermNetLayer
  The information needed to apply one layer of a permutation network.
- class helib::PermNetwork
  A full permutation network.

Namespaces

- helib

Typedefs

- typedef NTL::Vec< long > helib::Permut
  A simple permutation is just a vector with p[i]=\pi_i.
- typedef FullBinaryTree< SubDimension > helib::OneGeneratorTree

Functions

- template<typename T >
  void helib::applyPermToVec (NTL::Vec< T > &out, const NTL::Vec< T > &in, const Permut &p1)
  Apply a permutation to a std::vector, out[i]=in[p1[i]] (NOT in-place)
- template<typename T >
  void helib::applyPermToVec (std::vector< T > &out, const std::vector< T > &in, const Permut &p1)
- template<typename T >
  void helib::applyPermsToVec (NTL::Vec< T > &out, const NTL::Vec< T > &in, const Permut &p2, const Permut &p1)
  Apply two permutations to a std::vector out[i]=in[p2[p1[i]]] (NOT in-place)
- template<typename T >
  void helib::applyPermsToVec (std::vector< T > &out, const std::vector< T > &in, const Permut &p2, const Permut &p1)
- void helib::randomPerm (Permut &perm, long n)
  A random size-n permutation.
- std::ostream & helib::operator<< (std::ostream &s, const ColPerm &p)
- void helib::breakPermByDim (std::vector< ColPerm > &out, const Permut &pi, const CubeSignature &sig)
  Takes a permutation pi over m-dimensional cube C=Z_{n1} x...x Z_{nm} and expresses pi as a product pi = rho_↩ {2m-1} o ... o rho_2 o rho_1 where each rho_i is a column permutation along one dimension. Specifically for i<m, the permutations rho_i and rho_{2(m-1)-i} permute the i'th dimension.

8.34.1 Detailed Description

Permutations over Hypercubes and their slices.

8.35 /HElib/include/helib/PGFFT.h File Reference

```
#include <vector>
#include <complex>
```

Classes

- class helib::PGFFT
- class helib::PGFFT::aligned_allocator< T >

Namespaces

- helib

8.36 /HElib/include/helib/polyEval.h File Reference

Homomorphic Polynomial Evaluation.

```
#include <helib/Context.h>
#include <helib/Ctxt.h>
```

Classes

- class helib::DynamicCtxtPowers

  Store powers of X, compute them dynamically as needed.

Namespaces

- helib

Functions

- void helib::polyEval (Ctxt &ret, NTL::ZZX poly, const Ctxt &x, long k=0)

  Evaluate a cleartext polynomial on an encrypted input.
- void helib::polyEval (Ctxt &ret, const NTL::Vec< Ctxt > &poly, const Ctxt &x)

  Evaluate an encrypted polynomial on an encrypted input.

8.36.1 Detailed Description

Homomorphic Polynomial Evaluation.

8.37 /HElib/include/helib/PolyMod.h File Reference

Underlying slot type structure of BGV ptxts.

```
#include <NTL/ZZX.h>
#include <vector>
#include <memory>
#include <helib/PolyModRing.h>
```

Classes

- class helib::PolyMod

  An object that contains an `NTL::ZZX` polynomial along with a coefficient modulus `p2r` and a polynomial modulus `G`.

Namespaces

- helib

8.37.1 Detailed Description

Underlying slot type structure of BGV ptxts.

8.38 /HElib/include/helib/PolyModRing.h File Reference

Definition of the plaintext slot algebraic ring.

```
#include <NTL/ZZX.h>
#include <NTL/ZZ_p.h>
#include <vector>
```

Classes

- struct helib::PolyModRing

  Lightweight type for describing the structure of a single slot of the plaintext space.

Namespaces

- helib

8.38.1 Detailed Description

Definition of the plaintext slot algebraic ring.

8.39 /HElib/include/helib/powerful.h File Reference

The "powerful basis" of a cyclotomic ring.

```
#include <helib/NumbTh.h>
#include <helib/clonedPtr.h>
#include <helib/bluestein.h>
#include <helib/hypercube.h>
#include <helib/DoubleCRT.h>
#include <helib/Context.h>
```

Classes

- class helib::PowerfulTranslationIndexes

  Holds index tables for translation between powerful and zz_pX.
- class helib::PowerfulConversion

  Conversion between powerful representation in R_m/(q) and zz_pX.
- class helib::PowerfulDCRT

  Conversion between powerful representation, DoubleCRT, and ZZX.

Namespaces

- helib

8.39.1 Detailed Description

The "powerful basis" of a cyclotomic ring.

8.40 /HElib/include/helib/primeChain.h File Reference

handling the chain of moduli

```
#include <vector>
#include <helib/IndexSet.h>
```

Classes

- class helib::ModuliSizes

  A helper class to map required modulo-sizes to primeSets.

Namespaces

- helib

Functions

- std::ostream & helib::operator<< (std::ostream &s, const ModuliSizes::Entry &e)
- std::istream & helib::operator>> (std::istream &s, ModuliSizes::Entry &e)
- void helib::write (std::ostream &s, const ModuliSizes::Entry &e)
- void helib::read (std::istream &s, ModuliSizes::Entry &e)

8.40.1 Detailed Description

handling the chain of moduli

8.41 /HElib/include/helib/PtrMatrix.h File Reference

Convenience class templates providing a unified interface for a matrix of objects, returning pointers to these objects.

```
#include <initializer_list>
#include <helib/PtrVector.h>
```

Classes

- struct helib::PtrMatrix< T >

  An abstract class for an array of PtrVectors.
- struct helib::PtrMatrix_Vec< T >

  An implementation of PtrMatrix using Vec< Vec<T> >
- struct helib::PtrMatrix_ptVec< T >

  An implementation of PtrMatrix using Vec< Vec<T> >*
- struct helib::PtrMatrix_vector< T >

  An implementation of PtrMatrix using vector< vector<T> >
- struct helib::PtrMatrix_ptvector< T >

  An implementation of PtrMatrix using vector< vector<T> >*

Namespaces

- helib

Functions

- template<typename T >
  long helib::lsize (const PtrMatrix< T > &v)
- template<typename T >
  void helib::resize (PtrMatrix< T > &v, long newSize)
- template<typename T >
  void helib::setLengthZero (PtrMatrix< T > &v)
- template<typename T >
  const T * helib::ptr2nonNull (std::initializer_list< const PtrVector< T > * > list)

8.41.1 Detailed Description

Convenience class templates providing a unified interface for a matrix of objects, returning pointers to these objects.

8.42 /HElib/include/helib/PtrVector.h File Reference

Convenience class templates providing a unified interface for a collection of objects, returning pointers to these objects.

```
#include <stdexcept>
#include <climits>
#include <vector>
#include <NTL/vector.h>
#include <helib/assertions.h>
#include <helib/apiAttributes.h>
```

Classes

- struct helib::PtrVector< T >

  Abstract class for an array of objects.
- struct helib::PtrVector_VecPt< T >

  An implementation of PtrVector using Vec<T∗>
- struct helib::PtrVector_vectorPt< T >

  An implementation of PtrVector using vector<T∗>
- struct helib::PtrVector_VecT< T >

  An implementation of PtrVector using Vec<T>
- struct helib::PtrVector_vectorT< T >

  An implementation of PtrVector using vector<T>
- struct helib::PtrVector_slice< T >

  An implementation of PtrVector as a slice of another PtrVector.
- struct helib::PtrVector_Singleton< T >

  An implementation of PtrVector from a single T object.

Namespaces

- helib

Functions

- template<typename T >
  long helib::lsize (const PtrVector< T > &v)
- template<typename T >
  void helib::setLengthZero (PtrVector< T > &v)
- template<typename T >
  void helib::resize (PtrVector< T > &v, long newSize, const T &val)
- template<typename T >
  void helib::resize (PtrVector< T > &v, long newSize, const T ∗val)
- template<typename V1 , typename V2 >
  void helib::vecCopy (V1 &v1, const V2 &v2, long sizeLimit=0)
- template<typename V , typename T >
  void helib::vecCopy (V &v1, const PtrVector< T > &v2, long sizeLimit=0)
- template<typename V , typename T >
  void helib::vecCopy (PtrVector< T > &v1, const V &v2, long sizeLimit=0)
- template<typename T >
  void helib::vecCopy (PtrVector< T > &v1, const PtrVector< T > &v2, long sizeLimit=0)

8.42.1 Detailed Description

Convenience class templates providing a unified interface for a collection of objects, returning pointers to these objects.

8.43 /HElib/include/helib/Ptxt.h File Reference

Plaintext object parameterised on CKKS and BGV schemes. Also contains definition of `CKKS` and `BGV` structs.

```
#include <type_traits>
#include <vector>
#include <algorithm>
#include <numeric>
#include <iomanip>
#include <helib/Context.h>
#include <helib/EncryptedArray.h>
#include <helib/assertions.h>
#include <helib/PolyMod.h>
```

Classes

- struct helib::CKKS

    Type for CKKS scheme, to be used as template parameter.
- struct helib::BGV

    Type for BGV scheme, to be used as template parameter.
- class helib::Ptxt

    An object that mimics the functionality of the `Ctxt` object, and acts as a convenient entry point for inputting/encoding data which is to be encrypted.

Namespaces

- helib

Functions

- template< typename From , typename Scheme >
  std::vector< typename Scheme::SlotType > helib::convertDataToSlotVector (const std::vector< From > &data, const Context &context)

    Converts `std::vector<From>` to `std::vector<Scheme::SlotType>`.
- template< typename Scheme >
  void helib::innerProduct (Ptxt< Scheme > &result, const std::vector< Ptxt< Scheme >> &first_vec, const std::vector< Ptxt< Scheme >> &second_vec)

    Free function that computes the inner product of two vectors of `Ptxt`.

8.43.1 Detailed Description

Plaintext object parameterised on CKKS and BGV schemes. Also contains definition of `CKKS` and `BGV` structs.

8.44 /HElib/include/helib/randomMatrices.h File Reference

implementation of random matrices of various forms, used for testing

```
#include <helib/matmul.h>
#include <NTL/BasicThreadPool.h>
```

Classes

- class helib::RandomMatrix< type >
- class helib::RandomMultiMatrix< type >
- class helib::RandomBlockMatrix< type >
- class helib::RandomMultiBlockMatrix< type >
- class helib::RandomFullMatrix< type >
- class helib::RandomFullBlockMatrix< type >

Namespaces

- helib

Functions

- MatMul1D * helib::buildRandomMatrix (const EncryptedArray &ea, long dim)
- MatMul1D * helib::buildRandomMultiMatrix (const EncryptedArray &ea, long dim)
- BlockMatMul1D * helib::buildRandomBlockMatrix (const EncryptedArray &ea, long dim)
- BlockMatMul1D * helib::buildRandomMultiBlockMatrix (const EncryptedArray &ea, long dim)
- MatMulFull * helib::buildRandomFullMatrix (const EncryptedArray &ea)
- BlockMatMulFull * helib::buildRandomFullBlockMatrix (const EncryptedArray &ea)

8.44.1 Detailed Description

implementation of random matrices of various forms, used for testing

8.45 /HElib/include/helib/range.h File Reference

Classes

- class helib::general_range< T >
- class helib::general_range< T >::iterator

Namespaces

- helib

Functions

- general_range< long > helib::range (long n)
- general_range< long > helib::range (long m, long n)

8.46 /HElib/include/helib/recryption.h File Reference

Define some data structures to hold recryption data.

```
#include <helib/NumbTh.h>
```

Classes

- class helib::RecryptData

  A structure to hold recryption-related data inside the Context.
- class helib::ThinRecryptData

  Same as above, but for "thin" bootstrapping, where the slots are assumed to contain constants.

Namespaces

- helib

Macros

- #define HELIB_MIN_CAP_FRAC (2.0 / 3.0)

Variables

- long helib::thinRecrypt_initial_level
- long helib::fhe_force_chen_han = 0
- long helib::printFlag

8.46.1 Detailed Description

Define some data structures to hold recryption data.

8.46.2 Macro Definition Documentation

8.46.2.1 HELIB_MIN_CAP_FRAC

```
#define HELIB_MIN_CAP_FRAC (2.0 / 3.0)
```

8.47 /HElib/include/helib/replicate.h File Reference

Procedures for replicating a ciphertext slot across a full ciphertext.

```
#include <helib/EncryptedArray.h>
#include <helib/Ptxt.h>
```

Classes

- class helib::ReplicateHandler

    An abstract class to handle call-backs to get the output of replicate.

Namespaces

- helib

Functions

- void helib::replicate (const EncryptedArray &ea, Ctxt &ctx, long pos)

    The value in slot #pos is replicated in all other slots. On an n-slot ciphertext, this algorithm performs O(log n) 1D rotations.
- void helib::replicate0 (const EncryptedArray &ea, Ctxt &ctxt, long pos)

    A lower-level routine. Same as replicate, but assumes all slots are zero except slot #pos.
- void helib::replicateAll (const EncryptedArray &ea, const Ctxt &ctxt, ReplicateHandler ∗handler, long rec←Bound=64, RepAuxDim ∗repAuxPtr=nullptr)
- void helib::replicateAll (std::vector< Ctxt > &v, const EncryptedArray &ea, const Ctxt &ctxt, long rec←Bound=64, RepAuxDim ∗repAuxPtr=nullptr)
- template<typename Scheme >
  void helib::replicateAll (std::vector< Ptxt< Scheme >> &v, const EncryptedArray &, const Ptxt< Scheme > &ptxt)

    Generate a vector of plaintexts with each slot replicated in each plaintext.
- void helib::replicateAllOrig (const EncryptedArray &ea, const Ctxt &ctxt, ReplicateHandler ∗handler, RepAux ∗repAuxPtr=nullptr)
- void helib::replicate (const EncryptedArray &ea, PlaintextArray &pa, long i)
- template<typename Scheme >
  void helib::replicate (const EncryptedArray &, Ptxt< Scheme > &ptxt, long i)

    Replicate single slot of a `Ptxt` object across all of its slots.

Variables

- NTL_THREAD_LOCAL bool helib::replicateVerboseFlag = false

8.47.1 Detailed Description

Procedures for replicating a ciphertext slot across a full ciphertext.

This module implements a recursive, O(1)-amortized algorithm for replications. On an input ciphertext that encrypts (x_1, ..., x_n), we generate the n encrypted std::vectors (x_1, ..., x_1), ..., (x_n, ..., x_n), in that order.

To process the output std::vectors, a "call back" mechanism is used (so that we do not need to generate them all, and instead can return them one by one). For this purpose, the caller should pass a pointer to a class derived from the purely abstract class ReplicateHandler.

The replication procedures are meant to be used for linear algebra operation where a matrix-std::vector multiplication can be implemented for example by replicating each entry of the std::vector as a stand-alone ciphertext, then use the SIMD operations on these ciphertexts.

8.48 /HElib/include/helib/sample.h File Reference

```
#include <vector>
#include <NTL/xdouble.h>
#include <NTL/ZZX.h>
#include <NTL/ZZ_pX.h>
#include <helib/zzX.h>
```

Namespaces

- helib

Functions

- void helib::sampleSmall (zzX &poly, long n, double prob=0.5)
- void helib::sampleSmall (NTL::ZZX &poly, long n, double prob=0.5)
- void helib::sampleHWt (zzX &poly, long n, long Hwt=100)

  Sample a degree-(n-1) poly as above, with only Hwt nonzero coefficients.
- void helib::sampleHWt (NTL::ZZX &poly, long n, long Hwt=100)
- void helib::sampleGaussian (zzX &poly, long n, double stdev)

  Sample polynomials with Gaussian coefficients.
- void helib::sampleGaussian (NTL::ZZX &poly, long n, double stdev)
- void helib::sampleUniform (zzX &poly, long n, long B=100)

  Sample a degree-(n-1) ZZX, with coefficients uniform in [-B,B].
- void helib::sampleUniform (NTL::ZZX &poly, long n, const NTL::ZZ &B=NTL::ZZ(100L))
- void helib::sampleGaussian (std::vector< double > &dvec, long n, double stdev)

  Choose a vector of continuous Gaussians.
- double helib::sampleHWt (zzX &poly, const Context &context, long Hwt=100)
- double helib::sampleHWtBounded (zzX &poly, const Context &context, long Hwt=100)
- double helib::sampleHWtBoundedEffectiveBound (const Context &context, long Hwt=100)
- double helib::sampleSmall (zzX &poly, const Context &context)
- double helib::sampleSmallBounded (zzX &poly, const Context &context)
- double helib::sampleGaussian (zzX &poly, const Context &context, double stdev)
- double helib::sampleGaussianBounded (zzX &poly, const Context &context, double stdev)
- double helib::sampleUniform (zzX &poly, const Context &context, long B=100)
- NTL::xdouble helib::sampleUniform (NTL::ZZX &poly, const Context &context, const NTL::ZZ &B=NTL::↩ ZZ(100L))
- void helib::reduceModPhimX (zzX &poly, const PAlgebra &palg)
- const NTL::zz_pXModulus & helib::getPhimXMod (const PAlgebra &palg)

- double helib::boundFreshNoise (long m, long phim, double sigma, double epsilon=9e-13)
- double helib::boundRoundingNoise (long m, long phim, long p2r, double epsilon=9e-13)

8.48.1 Detailed Description

- implementing various sampling routines

8.49 /HElib/include/helib/tableLookup.h File Reference

Code for homomorphic table lookup and fixed-point functions.

```
#include <functional>
#include <helib/EncryptedArray.h>
#include <helib/CtPtrs.h>
```

Namespaces

- helib

Functions

- void helib::computeAllProducts (CtPtrs &products, const CtPtrs &array, std::vector< zzX > *unpackSlotEncoding=nullptr)
- void helib::tableLookup (Ctxt &out, const std::vector< zzX > &table, const CtPtrs &idx, std::vector< zzX > *unpackSlotEncoding=nullptr)
- void helib::tableWriteIn (const CtPtrs &table, const CtPtrs &idx, std::vector< zzX > *unpackSlotEncoding=nullptr)
- void helib::buildLookupTable (std::vector< zzX > &T, std::function< double(double)> f, long nbits_in, long scale_in, long sign_in, long nbits_out, long scale_out, long sign_out, const EncryptedArray &ea)

  Built a table-lookup for a function in fixed-point representation.

8.49.1 Detailed Description

Code for homomorphic table lookup and fixed-point functions.

8.50 /HElib/include/helib/timing.h File Reference

Utility functions for measuring time.

```
#include <helib/NumbTh.h>
#include <helib/multicore.h>
```

Classes

- class helib::FHEtimer

  A simple class to accumulate time.

Namespaces

- helib

Macros

- #define HELIB_STRINGIFY(x) #x
- #define HELIB_TOSTRING(x) HELIB_STRINGIFY(x)
- #define HELIB_AT __FILE__ ":" HELIB_TOSTRING(__LINE__)
- #define HELIB_stringify_aux(s) #s
- #define HELIB_stringify(s) HELIB_stringify_aux(s)
- #define HELIB_TIMER_START
- #define HELIB_TIMER_STOP _local_auto_timer.stop()
- #define HELIB_NTIMER_START(n)
- #define HELIB_NTIMER_STOP(n) _named_local_auto_timer##n.stop();

Functions

- void helib::registerTimer (FHEtimer ∗timer)
- unsigned long helib::GetTimerClock ()
- void helib::setTimersOn ()
- void helib::setTimersOff ()
- bool helib::areTimersOn ()
- const FHEtimer ∗ helib::getTimerByName (const char ∗name)
- void helib::resetAllTimers ()
- void helib::printAllTimers (std::ostream &str=std::cerr)

  Print the value of all timers to stream.
- bool helib::printNamedTimer (std::ostream &str, const char ∗name)

8.50.1 Detailed Description

Utility functions for measuring time.

This module contains some utility functions for measuring the time that various methods take to execute. To use it, we insert the macro HELIB_TIMER_START at the beginning of the method(s) that we want to time and HELIB←_TIMER_STOP at the end, then the main program needs to call the function setTimersOn() to activate the timers and setTimersOff() to pause them. To obtain the value of a given timer (in seconds), the application can use the function getTime4func(const char ∗fncName), and the function printAllTimers() prints the values of all timers to an output stream.

Using this method we can have at most one timer per method/function, and the timer is called by the same name as the function itself (using the built-in macro __func__). We can also use the "lower level" methods startFH←Etimer(name), stopFHEtimer(name), and resetFHEtimer(name) to add timers with arbitrary names (not necessarily associated with functions).

8.50.2 Macro Definition Documentation

8.50.2.1 HELIB_AT

```
#define HELIB_AT __FILE__ ":" HELIB_TOSTRING(__LINE__)
```

8.50.2.2 HELIB_NTIMER_START

```
#define HELIB_NTIMER_START(
              n )
```

Value:

```
static helib::FHEtimer _named_local_timer##n(#n, HELIB_AT);                \
helib::auto_timer _named_local_auto_timer##n(&_named_local_timer##n)
```

8.50.2.3 HELIB_NTIMER_STOP

```
#define HELIB_NTIMER_STOP(
              n ) _named_local_auto_timer##n.stop();
```

8.50.2.4 HELIB_stringify

```
#define HELIB_stringify(
              s ) HELIB_stringify_aux(s)
```

8.50.2.5 HELIB_STRINGIFY

```
#define HELIB_STRINGIFY(
              x ) #x
```

8.50.2.6 HELIB_stringify_aux

```
#define HELIB_stringify_aux(
              s ) #s
```

8.50.2.7 HELIB_TIMER_START

```
#define HELIB_TIMER_START
```

Value:

```
static helib::FHEtimer _local_timer(__func__, HELIB_AT);                    \
helib::auto_timer _local_auto_timer(&_local_timer)
```

8.50.2.8 HELIB_TIMER_STOP

```
#define HELIB_TIMER_STOP _local_auto_timer.stop()
```

8.50.2.9 HELIB_TOSTRING

```
#define HELIB_TOSTRING(
             x ) HELIB_STRINGIFY(x)
```

8.51 /HElib/include/helib/zzX.h File Reference

```
#include <NTL/vector.h>
#include <NTL/lzz_pX.h>
#include <NTL/GF2X.h>
```

Namespaces

- helib

Typedefs

- typedef NTL::Vec< long > helib::zzX

Functions

- bool helib::IsZero (const zzX &a)
- void helib::clear (zzX &a)
- void helib::convert (NTL::zz_pX &x, const zzX &a)
- void helib::add (zzX &res, const zzX &a, const zzX &b)
- zzX helib::operator+ (const zzX &a, const zzX &b)
- zzX & helib::operator+= (zzX &a, const zzX &b)
- void helib::div (zzX &res, const zzX &a, long b)
- zzX helib::operator/ (const zzX &a, long b)
- zzX & helib::operator/= (zzX &a, long b)
- void helib::mul (zzX &res, const zzX &a, long b)
- zzX helib::operator* (const zzX &a, long b)
- zzX & helib::operator*= (zzX &a, long b)
- void helib::normalize (zzX &f)
- const NTL::zz_pXModulus & helib::getPhimXMod (const PAlgebra &palg)
- void helib::reduceModPhimX (zzX &poly, const PAlgebra &palg)
- void helib::MulMod (zzX &res, const zzX &a, const zzX &b, const PAlgebra &palg)
- zzX helib::MulMod (const zzX &a, const zzX &b, const PAlgebra &palg)
- zzX helib::balanced_zzX (const NTL::zz_pX &f)
- zzX helib::balanced_zzX (const NTL::GF2X &f)

8.51.1 Detailed Description

- manipulating polynomials with single-precision coefficient It is assumed that the result is also single-precision

8.52 /HElib/src/BenesNetwork.cpp File Reference

```
#include <NTL/lzz_pXFactoring.h>
#include <helib/EncryptedArray.h>
#include <cstdlib>
#include <list>
#include <sstream>
#include <memory>
#include <NTL/vector.h>
#include <helib/NumbTh.h>
#include <helib/permutations.h>
```

Namespaces

- helib

8.53 /HElib/src/binaryArith.cpp File Reference

Implementing integer addition, multiplication in binary representation.

```
#include <numeric>
#include <climits>
#include <map>
#include <algorithm>
#include <stdexcept>
#include <atomic>
#include <mutex>
#include <NTL/BasicThreadPool.h>
#include <helib/binaryArith.h>
```

Classes

- class helib::DAGnode

  A node in an addition-DAG structure.
- class helib::ScratchCell

  A class to help manage the allocation of temporary Ctxt objects.
- class helib::AddDAG

  A class representing the logic of the order of bit products when adding two integers.
- struct helib::PtrMatrix_PtPtrVector< T >

  An implementation of PtrMatrix using vector< PtrVector<T> >*

Namespaces

- helib

Macros

- #define BPL_ESTIMATE (30)

Typedefs

- typedef std::pair< long, long > helib::NodeIdx

Functions

- long helib::defaultPmiddle (long delta)
- long helib::defaultQmiddle (long delta)
- void helib::packedRecrypt (const CtPtrs &a, const CtPtrs &b, std::vector< zzX > *unpackSlotEncoding)

  Function for packed recryption to recrypt multiple numbers.
- std::vector< long > helib::longToBitVector (long num, long bitSize)

  Returns a number as a vector of bits with LSB on the left.
- void helib::binaryMask (CtPtrs &binaryNums, const Ctxt &mask)

  Zeroes the slots of `binaryNums` where the corresponding slot of `mask` is 0.
- void helib::binaryCond (CtPtrs &output, const Ctxt &cond, const CtPtrs &trueValue, const CtPtrs &falseValue)

  Implementation of `output = cond * trueValue + (1 - cond) * falseValue`.
- void helib::concatBinaryNums (CtPtrs &output, const CtPtrs &a, const CtPtrs &b)

  Concatenates two binary numbers into a single `CtPtrs` object. E.g. If `a=10111`, `b=00101` then `output = 1011100101`.
- void helib::splitBinaryNums (CtPtrs &leftSplit, CtPtrs &rightSplit, const CtPtrs &input)

  Splits a single binary number into two binary numbers `leftSplit` and `rightSplit`.
- void helib::leftBitwiseShift (CtPtrs &output, const CtPtrs &input, const long shamt)

  Left shift `input` by `shamt`.
- void helib::bitwiseRotate (CtPtrs &output, const CtPtrs &input, long rotamt)

  Rotate `input` by `rotamt`.
- void helib::bitwiseXOR (CtPtrs &output, const CtPtrs &lhs, const CtPtrs &rhs)

  Compute a bitwise XOR between `lhs` and `rhs`.
- void helib::bitwiseOr (CtPtrs &output, const CtPtrs &lhs, const CtPtrs &rhs)

  Compute a bitwise OR between `lhs` and `rhs`.
- void helib::bitwiseAnd (CtPtrs &output, const CtPtrs &lhs, const CtPtrs &rhs)

  Compute a bitwise AND between `lhs` and `rhs`.
- void helib::bitwiseAnd (CtPtrs &output, const CtPtrs &input, const std::vector< long > mask)

  Compute a bitwise AND between `input` and a `std::vector<long>`.
- void helib::bitwiseNot (CtPtrs &output, const CtPtrs &input)

  Compute a bitwise NOT of `input`.
- void helib::addTwoNumbers (CtPtrs &sum, const CtPtrs &lhs, const CtPtrs &rhs, long sizeLimit=0, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Adds two numbers in binary representation where each ciphertext of the input vector contains a bit.
- void helib::negateBinary (CtPtrs &negation, const CtPtrs &input)

  Negates a number in binary 2's complement representation.
- void helib::subtractBinary (CtPtrs &difference, const CtPtrs &lhs, const CtPtrs &rhs, std::vector< zzX > *unpackSlotEncoding=nullptr)

Subtracts `rhs` from `lhs` where `lhs`, `rhs` are in 2's complement.

- void helib::addManyNumbers (CtPtrs &sum, CtPtrMat &numbers, long sizeLimit=0, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Sum an arbitrary amount of numbers in binary representation.
- void helib::multTwoNumbers (CtPtrs &product, const CtPtrs &lhs, const CtPtrs &rhs, bool rhsTwosComplement=false, long sizeLimit=0, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Multiply two numbers in binary representation where each ciphertext of the input vector contains a bit.
- long helib::fifteenOrLess4Four (const CtPtrs &out, const CtPtrs &in, long sizeLimit=4)

  Add together up to fifteen {0,1} integers, producing a 4-bit counter.
- void helib::decryptBinaryNums (std::vector< long > &pNums, const CtPtrs &eNums, const SecKey &sKey, const EncryptedArray &ea, bool twosComplement=false, bool allSlots=true)

  Decrypt the binary numbers that are encrypted in eNums.

8.53.1 Detailed Description

Implementing integer addition, multiplication in binary representation.

8.53.2 Macro Definition Documentation

8.53.2.1 BPL_ESTIMATE

```
#define BPL_ESTIMATE (30)
```

8.54 /HElib/src/binaryCompare.cpp File Reference

Implementing integer comparison in binary representation.

```
#include <algorithm>
#include <NTL/BasicThreadPool.h>
#include <helib/binaryArith.h>
```

Namespaces

- helib

Macros

- #define BPL_ESTIMATE (30)

Functions

- void helib::runningSums (CtPtrs &v)
- void helib::compareTwoNumbersImplementation (CtPtrs &max, CtPtrs &min, Ctxt &mu, Ctxt &ni, const CtPtrs &aa, const CtPtrs &bb, bool twosComplement, std::vector< zzX > *unpackSlotEncoding, bool cmp_only)
- void helib::compareTwoNumbers (CtPtrs &max, CtPtrs &min, Ctxt &mu, Ctxt &ni, const CtPtrs &a, const CtPtrs &b, bool twosComplement=false, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Compares two integers in binary `a`, `b`. Returns `max(a, b)`, `min(a, b)` and indicator bits `mu`=(`a`>`b`) and `ni`=(`a`<`b`)
- void helib::compareTwoNumbers (Ctxt &mu, Ctxt &ni, const CtPtrs &a, const CtPtrs &b, bool twosComplement=false, std::vector< zzX > *unpackSlotEncoding=nullptr)

  Compares two integers in binary `a`, `b`. Returns only indicator bits `mu`=(`a`>`b`) and `ni`=(`a`<`b`).

8.54.1 Detailed Description

Implementing integer comparison in binary representation.

8.54.2 Macro Definition Documentation

8.54.2.1 BPL_ESTIMATE

```
#define BPL_ESTIMATE (30)
```

8.55 /HElib/src/binio.cpp File Reference

```
#include <helib/binio.h>
#include <helib/assertions.h>
#include <cstring>
#include <sys/types.h>
```

Namespaces

- helib

Functions

- int helib::readEyeCatcher (std::istream &str, const char ∗expect)
- void helib::writeEyeCatcher (std::ostream &str, const char ∗eye)
- long helib::read_raw_int (std::istream &str)
- int helib::read_raw_int32 (std::istream &str)
- void helib::write_raw_int (std::ostream &str, long num)
- void helib::write_raw_int32 (std::ostream &str, int num)
- void helib::write_ntl_vec_long (std::ostream &str, const NTL::vec_long &vl, long intSize=BINIO_64BIT)
- void helib::read_ntl_vec_long (std::istream &str, NTL::vec_long &vl)
- void helib::write_raw_double (std::ostream &str, const double d)
- double helib::read_raw_double (std::istream &str)
- void helib::write_raw_xdouble (std::ostream &str, const NTL::xdouble xd)
- NTL::xdouble helib::read_raw_xdouble (std::istream &str)
- void helib::write_raw_ZZ (std::ostream &str, const NTL::ZZ &zz)
- void helib::read_raw_ZZ (std::istream &str, NTL::ZZ &zz)
- template<> void helib::read_raw_vector< long > (std::istream &str, std::vector< long > &v)
- template<> void helib::write_raw_vector< long > (std::ostream &str, const std::vector< long > &v)
- template<> void helib::read_raw_vector< double > (std::istream &str, std::vector< double > &v)
- template<> void helib::write_raw_vector< double > (std::ostream &str, const std::vector< double > &v)

8.56 /HElib/src/bluestein.cpp File Reference

```
#include <helib/bluestein.h>
#include <helib/timing.h>
#include <helib/CModulus.h>
#include <helib/apiAttributes.h>
```

Namespaces

- helib

Macros

- #define NEW_BLUE (1)

Functions

- void helib::BluesteinInit (long n, const NTL::zz_p &root, NTL::zz_pX &powers, NTL::Vec< NTL::mulmod_precon_t > &powers_aux, NTL::fftRep &Rb)

    initialize bluestein
- void helib::BluesteinFFT (NTL::zz_pX &x, long n, UNUSED const NTL::zz_p &root, const NTL::zz_pX &powers, const NTL::Vec< NTL::mulmod_precon_t > &powers_aux, const NTL::fftRep &Rb)

8.56.1 Macro Definition Documentation

8.56.1.1 NEW_BLUE

```
#define NEW_BLUE (1)
```

8.57 /HElib/src/CModulus.cpp File Reference

```
#include <helib/CModulus.h>
#include <helib/timing.h>
```

Namespaces

- helib

Functions

- NTL::zz_pContext helib::BuildContext (long p, long maxroot)

8.58 /HElib/src/Context.cpp File Reference

```
#include <cstring>
#include <algorithm>
#include <helib/Context.h>
#include <helib/EvalMap.h>
#include <helib/powerful.h>
#include <helib/binio.h>
#include <helib/sample.h>
#include <helib/EncryptedArray.h>
#include <helib/PolyModRing.h>
```

Namespaces

- helib

Functions

- long helib::FindM (long k, long nBits, long c, long p, long d, long s, long chosen_m, bool verbose=false)

    Returns smallest parameter m satisfying various constraints:
- void helib::writeContextBaseBinary (std::ostream &str, const Context &context)

    write [m p r gens ords] data
- void helib::readContextBaseBinary (std::istream &s, unsigned long &m, unsigned long &p, unsigned long &r, std::vector< long > &gens, std::vector< long > &ords)

    read [m p r gens ords] data, needed to construct context
- std::unique_ptr< Context > helib::buildContextFromBinary (std::istream &str)
- void helib::writeContextBinary (std::ostream &str, const Context &context)
- void helib::readContextBinary (std::istream &str, Context &context)
- void helib::writeContextBase (std::ostream &s, const Context &context)

    write [m p r gens ords] data
- std::ostream & helib::operator<< (std::ostream &str, const Context &context)
- void helib::readContextBase (std::istream &s, unsigned long &m, unsigned long &p, unsigned long &r, std::vector< long > &gens, std::vector< long > &ords)

    read [m p r gens ords] data, needed to construct context
- std::unique_ptr< Context > helib::buildContextFromAscii (std::istream &str)
- std::istream & helib::operator>> (std::istream &str, Context &context)
- NTL::ZZX helib::getG (const EncryptedArray &ea)

8.59 /HElib/src/Ctxt.cpp File Reference

```
#include <NTL/BasicThreadPool.h>
#include <helib/binio.h>
#include <helib/timing.h>
#include <helib/Context.h>
#include <helib/Ctxt.h>
#include <helib/keySwitching.h>
#include <helib/CtPtrs.h>
#include <helib/EncryptedArray.h>
#include <helib/Ptxt.h>
#include <helib/debugging.h>
#include <helib/norms.h>
#include <helib/fhe_stats.h>
#include <helib/powerful.h>
```

Namespaces

- helib

Functions

- void helib::addSomePrimes (Ctxt &c)
- void helib::computeIntervalForMul (double &lo, double &hi, const Ctxt &ctxt1, const Ctxt &ctxt2)
- void helib::computeIntervalForSqr (double &lo, double &hi, const Ctxt &ctxt)
- std::istream & helib::operator>> (std::istream &str, SKHandle &handle)
- std::ostream & helib::operator<< (std::ostream &s, const CtxtPart &p)
- std::istream & helib::operator>> (std::istream &s, CtxtPart &p)

- std::ostream & helib::operator<< (std::ostream &str, const Ctxt &ctxt)
- std::istream & helib::operator>> (std::istream &str, Ctxt &ctxt)
- void helib::incrementalProduct (std::vector< Ctxt > &v)
- void helib::totalProduct (Ctxt &out, const std::vector< Ctxt > &v)
- void helib::innerProduct (Ctxt &result, const CtPtrs &v1, const CtPtrs &v2)
- void helib::innerProduct (Ctxt &result, const std::vector< Ctxt > &v1, const std::vector< Ctxt > &v2)
- void helib::innerProduct (Ctxt &result, const std::vector< Ctxt > &v1, const std::vector< DoubleCRT > &v2)

    Compute the inner product of a vectors of ciphertexts and a constant vector.
- void helib::innerProduct (Ctxt &result, const std::vector< Ctxt > &v1, const std::vector< NTL::ZZX > &v2)

Variables

- int helib::fhe_watcher = 0

8.60 /HElib/src/debugging.cpp File Reference

```
#include <NTL/xdouble.h>
#include <helib/debugging.h>
#include <helib/norms.h>
#include <helib/Context.h>
#include <helib/Ctxt.h>
#include <helib/EncryptedArray.h>
```

Namespaces

- helib

Functions

- double helib::realToEstimatedNoise (const Ctxt &ctxt, const SecKey &sk)
- double helib::log2_realToEstimatedNoise (const Ctxt &ctxt, const SecKey &sk)
- void helib::checkNoise (const Ctxt &ctxt, const SecKey &sk, const std::string &msg, double thresh=10.0)
- NTL::xdouble helib::embeddingLargestCoeff (const Ctxt &ctxt, const SecKey &sk)
- void helib::decryptAndPrint (std::ostream &s, const Ctxt &ctxt, const SecKey &sk, const EncryptedArray &ea, long flags=0)
- bool helib::decryptAndCompare (const Ctxt &ctxt, const SecKey &sk, const EncryptedArray &ea, const PlaintextArray &pa)
- void helib::rawDecrypt (NTL::ZZX &plaintxt, const std::vector< NTL::ZZX > &zzParts, const DoubleCRT &s↩ Key, long q=0)
- void helib::CheckCtxt (const Ctxt &c, const char ∗label)

    print to cerr some info about ciphertext

8.61 /HElib/src/DoubleCRT.cpp File Reference

```
#include <NTL/ZZVec.h>
#include <NTL/BasicThreadPool.h>
#include <helib/timing.h>
#include <helib/binio.h>
#include <helib/sample.h>
#include <helib/DoubleCRT.h>
#include <helib/Context.h>
#include <helib/norms.h>
#include <helib/fhe_stats.h>
```

Namespaces

- helib

Functions

- template DoubleCRT & helib::DoubleCRT::Op< DoubleCRT::AddFun > (const DoubleCRT &other, AddFun fun, bool matchIndexSets)
- template DoubleCRT & helib::DoubleCRT::Op< DoubleCRT::SubFun > (const DoubleCRT &other, SubFun fun, bool matchIndexSets)
- template DoubleCRT & helib::DoubleCRT::Op< DoubleCRT::MulFun > (const NTL::ZZ &num, MulFun fun)
- template DoubleCRT & helib::DoubleCRT::Op< DoubleCRT::AddFun > (const NTL::ZZ &num, AddFun fun)
- template DoubleCRT & helib::DoubleCRT::Op< DoubleCRT::SubFun > (const NTL::ZZ &num, SubFun fun)
- template DoubleCRT & helib::DoubleCRT::Op< DoubleCRT::MulFun > (const NTL::ZZX &poly, MulFun fun)
- template DoubleCRT & helib::DoubleCRT::Op< DoubleCRT::AddFun > (const NTL::ZZX &poly, AddFun fun)
- template DoubleCRT & helib::DoubleCRT::Op< DoubleCRT::SubFun > (const NTL::ZZX &poly, SubFun fun)
- std::ostream & helib::operator<< (std::ostream &str, const DoubleCRT &d)
- std::istream & helib::operator>> (std::istream &str, DoubleCRT &d)

8.62 /HElib/src/EaCx.cpp File Reference

```
#include <algorithm>
#include <type_traits>
#include <helib/zzX.h>
#include <helib/EncryptedArray.h>
#include <helib/timing.h>
#include <helib/clonedPtr.h>
#include <helib/norms.h>
#include <helib/debugging.h>
#include <helib/apiAttributes.h>
```

Namespaces

- helib

8.63 /HElib/src/EncryptedArray.cpp File Reference

```
#include <algorithm>
#include <helib/zzX.h>
#include <helib/EncryptedArray.h>
#include <helib/timing.h>
#include <helib/clonedPtr.h>
#include <helib/norms.h>
```

Classes

- class helib::rotate_pa_impl< type >
- class helib::shift_pa_impl< type >
- class helib::encode_pa_impl< type >
- class helib::random_pa_impl< type >
- class helib::decode_pa_impl< type >
- class helib::equals_pa_impl< type >
- class helib::add_pa_impl< type >
- class helib::sub_pa_impl< type >
- class helib::mul_pa_impl< type >
- class helib::negate_pa_impl< type >
- class helib::frobeniusAutomorph_pa_impl< type >
- class helib::applyPerm_pa_impl< type >
- class helib::print_pa_impl< type >

Namespaces

- helib

Functions

- EncryptedArrayBase ∗ helib::buildEncryptedArray (const Context &context, const PAlgebraMod &alMod, const NTL::ZZX &G=NTL::ZZX::zero())

  A "factory" for building EncryptedArrays.
- void helib::runningSums (const EncryptedArray &ea, Ctxt &ctxt)

  A ctxt that encrypts $(x_1, ..., x_n)$ *is replaced by an encryption of* $(y_1, ..., y_n)$*, where* $y_i = sum_{j \le i} x_j$.
- void helib::totalSums (const EncryptedArray &ea, Ctxt &ctxt)
- void helib::applyLinPoly1 (const EncryptedArray &ea, Ctxt &ctxt, const std::vector< NTL::ZZX > &C)
- void helib::applyLinPolyMany (const EncryptedArray &ea, Ctxt &ctxt, const std::vector< std::vector< NTL↩ ::ZZX >> &Cvec)
- template<typename P >
  void helib::applyLinPolyLL (Ctxt &ctxt, const std::vector< P > &encodedC, long d)
- template void helib::applyLinPolyLL (Ctxt &ctxt, const std::vector< zzX > &encodedC, long d)
- template void helib::applyLinPolyLL (Ctxt &ctxt, const std::vector< NTL::ZZX > &encodedC, long d)
- template void helib::applyLinPolyLL (Ctxt &ctxt, const std::vector< DoubleCRT > &encodedC, long d)
- void helib::rotate (const EncryptedArray &ea, PlaintextArray &pa, long k)
- void helib::shift (const EncryptedArray &ea, PlaintextArray &pa, long k)
- void helib::encode (const EncryptedArray &ea, PlaintextArray &pa, const std::vector< long > &array)
- void helib::encode (const EncryptedArray &ea, PlaintextArray &pa, const std::vector< NTL::ZZX > &array)
- void helib::encode (const EncryptedArray &ea, PlaintextArray &pa, long val)

- void helib::encode (const EncryptedArray &ea, PlaintextArray &pa, const NTL::ZZX &val)
- void helib::random (const EncryptedArray &ea, PlaintextArray &pa)
- void helib::decode (const EncryptedArray &ea, std::vector< long > &array, const PlaintextArray &pa)
- void helib::decode (const EncryptedArray &ea, std::vector< NTL::ZZX > &array, const PlaintextArray &pa)
- bool helib::equals (const EncryptedArray &ea, const PlaintextArray &pa, const PlaintextArray &other)
- bool helib::equals (const EncryptedArray &ea, const PlaintextArray &pa, const std::vector< long > &other)
- bool helib::equals (const EncryptedArray &ea, const PlaintextArray &pa, const std::vector< NTL::ZZX > &other)
- void helib::add (const EncryptedArray &ea, PlaintextArray &pa, const PlaintextArray &other)
- void helib::sub (const EncryptedArray &ea, PlaintextArray &pa, const PlaintextArray &other)
- void helib::mul (const EncryptedArray &ea, PlaintextArray &pa, const PlaintextArray &other)
- void helib::negate (const EncryptedArray &ea, PlaintextArray &pa)
- void helib::frobeniusAutomorph (const EncryptedArray &ea, PlaintextArray &pa, long j)
- void helib::frobeniusAutomorph (const EncryptedArray &ea, PlaintextArray &pa, const NTL::Vec< long > &vec)
- void helib::power (const EncryptedArray &ea, PlaintextArray &pa, long e)
- void helib::applyPerm (const EncryptedArray &ea, PlaintextArray &pa, const NTL::Vec< long > &pi)
- void helib::print (const EncryptedArray &ea, std::ostream &s, const PlaintextArray &pa)

8.64 /HElib/src/eqtesting.cpp File Reference

Useful functions for equality testing...

```
#include <NTL/lzz_pXFactoring.h>
#include <helib/timing.h>
#include <helib/EncryptedArray.h>
#include <helib/Ptxt.h>
#include <cstdio>
```

Namespaces

- helib

Functions

- void helib::mapTo01 (const EncryptedArray &ea, Ctxt &ctxt)
- template<typename Scheme >
  void helib::mapTo01 (const EncryptedArray &, Ptxt< Scheme > &ptxt)
- template void helib::mapTo01 (const EncryptedArray &, Ptxt< BGV > &ptxt)
- template void helib::mapTo01 (const EncryptedArray &, Ptxt< CKKS > &ptxt)
- void helib::fastPower (Ctxt &ctxt, long d)
- void helib::incrementalZeroTest (Ctxt *res[ ], const EncryptedArray &ea, const Ctxt &ctxt, long n)

8.64.1 Detailed Description

Useful functions for equality testing...

8.65 /HElib/src/EvalMap.cpp File Reference

```
#include <helib/EvalMap.h>
#include <helib/apiAttributes.h>
#include <NTL/lzz_pXFactoring.h>
#include <NTL/GF2XFactoring.h>
```

Namespaces

- helib

Functions

- void helib::RelaxedInv (NTL::Mat< NTL::zz_p > &x, const NTL::Mat< NTL::zz_p > &a)
- void helib::RelaxedInv (NTL::Mat< NTL::GF2 > &x, const NTL::Mat< NTL::GF2 > &a)
- void helib::TraceMap (NTL::GF2X &w, const NTL::GF2X &a, long d, const NTL::GF2XModulus &F, const NTL::GF2X &b)

8.66 /HElib/src/extractDigits.cpp File Reference

```
#include <NTL/ZZ.h>
#include <NTL/ZZ_p.h>
#include <helib/EncryptedArray.h>
#include <helib/polyEval.h>
#include <helib/debugging.h>
```

Namespaces

- helib

Functions

- void helib::extractDigits (std::vector< Ctxt > &digits, const Ctxt &c, long r=0)

  Extract the mod-p digits of a mod-p^r ciphertext.
- void helib::extendExtractDigits (std::vector< Ctxt > &digits, const Ctxt &c, long r, long e)

8.67 /HElib/src/fhe_stats.cpp File Reference

```
#include <helib/fhe_stats.h>
#include <helib/multicore.h>
#include <algorithm>
#include <utility>
#include <cstring>
```

Namespaces

- helib

Functions

- void helib::print_stats (std::ostream &s)
- const std::vector< double > * helib::fetch_saved_values (const char *)

8.68 /HElib/src/hypercube.cpp File Reference

```
#include <helib/hypercube.h>
#include <iomanip>
#include <NTL/lzz_p.h>
```

Namespaces

- helib

Functions

- template< typename T >
  void helib::getHyperColumn (NTL::Vec< T > &v, const ConstCubeSlice< T > &s, long pos)
- template< typename T >
  void helib::setHyperColumn (const NTL::Vec< T > &v, const CubeSlice< T > &s, long pos)
- template< typename T >
  void helib::setHyperColumn (const NTL::Vec< T > &v, const CubeSlice< T > &s, long pos, const T &val)
- template< typename T >
  void helib::print3D (const HyperCube< T > &c)
- template void helib::getHyperColumn (NTL::Vec< long > &v, const ConstCubeSlice< long > &s, long pos)
- template void helib::setHyperColumn (const NTL::Vec< long > &v, const CubeSlice< long > &s, long pos)
- template void helib::setHyperColumn (const NTL::Vec< long > &v, const CubeSlice< long > &s, long pos, const long &val)
- template void helib::print3D (const HyperCube< long > &c)
- template void helib::getHyperColumn (NTL::Vec< NTL::zz_p > &v, const ConstCubeSlice< NTL::zz_p > &s, long pos)
- template void helib::setHyperColumn (const NTL::Vec< NTL::zz_p > &v, const CubeSlice< NTL::zz_p > &s, long pos)
- template void helib::setHyperColumn (const NTL::Vec< NTL::zz_p > &v, const CubeSlice< NTL::zz_p > &s, long pos, const NTL::zz_p &val)
- template void helib::print3D (const HyperCube< NTL::zz_p > &c)

8.69 /HElib/src/IndexSet.cpp File Reference

```
#include <helib/IndexSet.h>
#include <helib/binio.h>
```

Namespaces

- helib

Functions

- IndexSet helib::operator| (const IndexSet &s, const IndexSet &t)
  union
- IndexSet helib::operator& (const IndexSet &s, const IndexSet &t)
  intersection
- IndexSet helib::operator^ (const IndexSet &s, const IndexSet &t)
  exclusive-or
- IndexSet helib::operator/ (const IndexSet &s, const IndexSet &t)
  set minus
- long helib::card (const IndexSet &s)
  Functional cardinality.
- bool helib::operator<= (const IndexSet &s1, const IndexSet &s2)
  Is s1 subset or equal to s2.
- bool helib::operator< (const IndexSet &s1, const IndexSet &s2)
  Is s1 strict subset of s2.
- bool helib::operator>= (const IndexSet &s1, const IndexSet &s2)
  Is s2 subset or equal to s2.
- bool helib::operator> (const IndexSet &s1, const IndexSet &s2)
  Is s2 strict subset of s1.
- std::ostream & helib::operator<< (std::ostream &str, const IndexSet &set)
- std::istream & helib::operator>> (std::istream &str, IndexSet &set)

8.70 /HElib/src/intraSlot.cpp File Reference

```
#include <memory>
#include <helib/replicate.h>
#include <helib/intraSlot.h>
```

Namespaces

- helib

Functions

- void helib::unpack (const CtPtrs &unpacked, const Ctxt &packed, const EncryptedArray &ea, const std::vector< zzX > &unpackSlotEncoding)
- long helib::unpack (const CtPtrs &unpacked, const CtPtrs &packed, const EncryptedArray &ea, const std::vector< zzX > &unpackSlotEncoding)
- void helib::repack (Ctxt &packed, const CtPtrs &unpacked, const EncryptedArray &ea)
- long helib::repack (const CtPtrs &packed, const CtPtrs &unpacked, const EncryptedArray &ea)
- void helib::packConstant (zzX &result, unsigned long data, long nbits, const EncryptedArray &ea)
- void helib::packConstants (zzX &result, const std::vector< unsigned long > &data, long nbits, const EncryptedArray &ea)
- void helib::unpackSlots (std::vector< unsigned long > &value, PlaintextArray &pa, const EncryptedArray &ea)

8.71 /HElib/src/keys.cpp File Reference

```
#include <queue>
#include <helib/keys.h>
#include <helib/timing.h>
#include <helib/EncryptedArray.h>
#include <helib/Ptxt.h>
#include <helib/binio.h>
#include <helib/sample.h>
#include <helib/norms.h>
#include <helib/apiAttributes.h>
#include <helib/fhe_stats.h>
```

Namespaces

- helib

Macros

- #define DECRYPT_ON_PWFL_BASIS

Functions

- double helib::RLWE1 (DoubleCRT &c0, const DoubleCRT &c1, const DoubleCRT &s, long p)

    Same as RLWE, but assumes that c1 is already chosen by the caller.
- double helib::RLWE (DoubleCRT &c0, DoubleCRT &c1, const DoubleCRT &s, long p, NTL::ZZ ∗prg↩ Seed=nullptr)
- std::ostream & helib::operator<< (std::ostream &str, const PubKey &pk)
- std::istream & helib::operator>> (std::istream &str, PubKey &pk)
- void helib::writePubKeyBinary (std::ostream &str, const PubKey &pk)
- void helib::readPubKeyBinary (std::istream &str, PubKey &pk)
- std::ostream & helib::operator<< (std::ostream &str, const SecKey &sk)
- std::istream & helib::operator>> (std::istream &str, SecKey &sk)
- void helib::writeSecKeyBinary (std::ostream &str, const SecKey &sk)
- void helib::readSecKeyBinary (std::istream &str, SecKey &sk)

8.71.1 Macro Definition Documentation

8.71.1.1 DECRYPT_ON_PWFL_BASIS

```
#define DECRYPT_ON_PWFL_BASIS
```

8.72 /HElib/src/keySwitching.cpp File Reference

A few strategies for generating key-switching matrices.

```
#include <unordered_set>
#include <NTL/ZZ.h>
#include <helib/permutations.h>
#include <helib/binio.h>
#include <helib/keySwitching.h>
#include <helib/keys.h>
#include <helib/apiAttributes.h>
```

Namespaces

- helib

Macros

- #define computeParams(context, m, i)

Functions

- std::ostream & helib::operator<< (std::ostream &str, const KeySwitch &matrix)

Strategies for generating key-switching matrices

These functions are implemented in KeySwitching.cpp

- long helib::KSGiantStepSize (long D)
  Function that returns number of baby steps. Used to keep this and matmul routines "in sync".
- void helib::addAllMatrices (SecKey &sKey, long keyID=0)
  Maximalistic approach: generate matrices s(X^e)->s(X) for all e in Zm.*
- void helib::addSome1DMatrices (SecKey &sKey, long bound=HELIB_KEYSWITCH_THRESH, long key←ID=0)
  *Generate some matrices of the form s(X^{g^i})->s(X), but not all. For a generator g whose order is larger than bound, generate only enough matrices for the giant-step/baby-step procedures (2*sqrt(ord(g))of them).*
- void helib::add1DMatrices (SecKey &sKey, long keyID=0)
  Generate all matrices s(X^{g^i})->s(X) for generators g of Zm /(p) and i<ord(g). If g has different orders in Zm* and Zm* /(p) then generate also matrices of the form s(X^{g^{-i}})->s(X)*
- void helib::addBSGS1DMatrices (SecKey &sKey, long keyID=0)
- void helib::addSomeFrbMatrices (SecKey &sKey, long bound=HELIB_KEYSWITCH_THRESH, long key←ID=0)
  Generate all/some Frobenius matrices of the form s(X^{p^i})->s(X)
- void helib::addFrbMatrices (SecKey &sKey, long keyID=0)
- void helib::addBSGSFrbMatrices (SecKey &sKey, long keyID=0)
- void helib::addMinimal1DMatrices (SecKey &sKey, long keyID=0)
  These routines just add a single matrix (or two, for bad dimensions)
- void helib::addMinimalFrbMatrices (SecKey &sKey, long keyID=0)
- void helib::addMatrices4Network (SecKey &sKey, const PermNetwork &net, long keyID=0)
- void helib::addTheseMatrices (SecKey &sKey, const std::set< long > &automVals, long keyID=0)
  Generate specific key-switching matrices, described by the given set.

8.72.1 Detailed Description

A few strategies for generating key-switching matrices.

8.72.2 Macro Definition Documentation

8.72.2.1 computeParams

```
#define computeParams(
                context,
                m,
                i )
```

Value:

```
bool native;                                                                    \
long ord, gi, g2md;                                                             \
NTL::mulmod_precon_t g2mdminv;                                                  \
if (i == context.zMStar.numOfGens()) { /* Frobenius matrices */                 \
  ord = context.zMStar.getOrdP();                                               \
  gi = context.zMStar.getP();                                                   \
  native = true;                                                                \
} else { /* one of the "regular" dimensions */                                  \
  ord = context.zMStar.OrderOf(i);                                              \
  gi = context.zMStar.ZmStarGen(i);                                             \
  native = context.zMStar.SameOrd(i);                                           \
  if (!native) {                                                                \
    g2md = PowerMod(gi, -ord, m); /* g^{-ord} mod m */                          \
    g2mdminv = PrepMulModPrecon(g2md, m);                                       \
  }                                                                             \
}                                                                               \
NTL::mulmod_precon_t giminv = PrepMulModPrecon(gi, m);
```

8.73 /HElib/src/matching.cpp File Reference

```
#include <helib/matching.h>
#include <queue>
```

Namespaces

- helib

Functions

- void helib::printFlow (FlowGraph &fg)
- long helib::maximum_flow (FlowGraph &fg, long src, long sink)

8.74 /HElib/src/matmul.cpp File Reference

```
#include <cstddef>
#include <tuple>
#include <algorithm>
#include <NTL/BasicThreadPool.h>
#include <helib/matmul.h>
#include <helib/norms.h>
#include <helib/fhe_stats.h>
#include <helib/apiAttributes.h>
```

Classes

- class helib::BasicAutomorphPrecon

  Pre-computation to speed many automorphism on the same ciphertext.
- class helib::GeneralAutomorphPrecon
- class helib::GeneralAutomorphPrecon_UNKNOWN
- class helib::GeneralAutomorphPrecon_FULL
- class helib::GeneralAutomorphPrecon_BSGS
- struct helib::ConstMultiplier
- struct helib::ConstMultiplier_DoubleCRT
- struct helib::ConstMultiplier_zzX
- struct helib::MatMul1D_derived_impl< type >
- struct helib::MatMul1DExec_construct< type >
- struct helib::BlockMatMul1D_derived_impl< type >
- struct helib::BlockMatMul1DExec_construct< type >
- class helib::MatMulFullHelper< type >
- struct helib::MatMulFullExec_construct< type >
- struct helib::MatMulFullExec_construct< type >::MatMulDimComp
- class helib::BlockMatMulFullHelper< type >
- struct helib::BlockMatMulFullExec_construct< type >
- struct helib::BlockMatMulFullExec_construct< type >::BlockMatMulDimComp
- struct helib::mul_MatMul1D_impl< type >
- struct helib::mul_BlockMatMul1D_impl< type >
- struct helib::mul_MatMulFull_impl< type >
- struct helib::mul_BlockMatMulFull_impl< type >

Namespaces

- helib

Macros

- #define ALT_MATMUL (1)
- #define HELIB_BSGS_MUL_THRESH HELIB_KEYSWITCH_THRESH
- #define HELIB_TRACE_THRESH (50)

Functions

- std::shared_ptr< GeneralAutomorphPrecon > helib::buildGeneralAutomorphPrecon (const Ctxt &ctxt, long dim, const EncryptedArray &ea)
- template<typename RX >
  std::shared_ptr< ConstMultiplier > helib::build_ConstMultiplier (const RX &poly)
- template<typename RX , typename type >
  std::shared_ptr< ConstMultiplier > helib::build_ConstMultiplier (const RX &poly, long dim, long amt, const EncryptedArrayDerived< type > &ea)
- void helib::MulAdd (Ctxt &x, const std::shared_ptr< ConstMultiplier > &a, const Ctxt &b)
- void helib::DestMulAdd (Ctxt &x, const std::shared_ptr< ConstMultiplier > &a, Ctxt &b)
- void helib::GenBabySteps (std::vector< std::shared_ptr< Ctxt >> &v, const Ctxt &ctxt, long dim, bool clean)
- void helib::mul (PlaintextArray &pa, const MatMul1D &mat)
- void helib::mul (PlaintextArray &pa, const BlockMatMul1D &mat)
- void helib::mul (PlaintextArray &pa, const MatMulFull &mat)
- void helib::mul (PlaintextArray &pa, const BlockMatMulFull &mat)
- void helib::traceMap (Ctxt &ctxt)

8.74.1 Macro Definition Documentation

8.74.1.1 ALT_MATMUL

```
#define ALT_MATMUL (1)
```

8.74.1.2 HELIB_BSGS_MUL_THRESH

```
#define HELIB_BSGS_MUL_THRESH HELIB_KEYSWITCH_THRESH
```

8.74.1.3 HELIB_TRACE_THRESH

```
#define HELIB_TRACE_THRESH (50)
```

8.75 /HElib/src/norms.cpp File Reference

```
#include <complex>
#include <cmath>
#include <algorithm>
#include <helib/NumbTh.h>
#include <helib/DoubleCRT.h>
#include <helib/norms.h>
#include <helib/PAlgebra.h>
#include <helib/fhe_stats.h>
```

Namespaces

- helib

Macros

- #define USE_HALF_FFT (1)
- #define USE_QUARTER_FFT (1)
- #define USE_TWO_QUARTERS (0)

Functions

- long helib::sumOfCoeffs (const zzX &f)
- NTL::ZZ helib::sumOfCoeffs (const NTL::ZZX &f)
- NTL::ZZ helib::sumOfCoeffs (const DoubleCRT &f)
- NTL::ZZ helib::largestCoeff (const NTL::ZZX &f)
- NTL::ZZ helib::largestCoeff (const NTL::Vec< NTL::ZZ > &f)
- NTL::ZZ helib::largestCoeff (const DoubleCRT &f)
- double helib::coeffsL2NormSquared (const zzX &f)

    The L2-norm of an element (in coefficient representation)
- NTL::xdouble helib::coeffsL2NormSquared (const NTL::ZZX &f)
- NTL::xdouble helib::coeffsL2NormSquared (const DoubleCRT &f)
- double helib::embeddingLargestCoeff (const std::vector< double > &f, const PAlgebra &palg)
- void helib::embeddingLargestCoeff_x2 (double &norm1, double &norm2, const std::vector< double > &f1, const std::vector< double > &f2, const PAlgebra &palg)
- double helib::embeddingLargestCoeff (const zzX &f, const PAlgebra &palg)
- NTL::xdouble helib::embeddingLargestCoeff (const NTL::ZZX &f, const PAlgebra &palg)
- void helib::CKKS_canonicalEmbedding (std::vector< cx_double > &v, const std::vector< double > &f, const PAlgebra &palg)
- void helib::CKKS_canonicalEmbedding (std::vector< cx_double > &v, const zzX &f, const PAlgebra &palg)
- void helib::CKKS_canonicalEmbedding (std::vector< cx_double > &v, const NTL::ZZX &f, const PAlgebra &palg)
- void helib::CKKS_embedInSlots (zzX &f, const std::vector< cx_double > &v, const PAlgebra &palg, double scaling)

8.75.1 Detailed Description

- computing various norms of ring elements

8.75.2 Macro Definition Documentation

8.75.2.1 USE_HALF_FFT

```
#define USE_HALF_FFT (1)
```

8.75.2.2 USE_QUARTER_FFT

```
#define USE_QUARTER_FFT (1)
```

8.75.2.3 USE_TWO_QUARTERS

```
#define USE_TWO_QUARTERS (0)
```

8.76 /HElib/src/NumbTh.cpp File Reference

```
#include <helib/NumbTh.h>
#include <helib/timing.h>
#include <fstream>
#include <cctype>
#include <algorithm>
```

Namespaces

- helib

Functions

- long helib::bitSetToLong (long bits, long bitSize)

  Considers `bits` *as a vector of bits and returns the value it represents when interpreted as a n-bit 2's complement number, where n is given by* `bitSize`*.*
- long helib::mcMod (long a, long b)

  Routines for computing mathematically correct mod and div.
- long helib::mcDiv (long a, long b)
- long helib::multOrd (long p, long m)

  Return multiplicative order of p modulo m, or 0 if GCD(p, m) != 1.
- long helib::computeProd (const NTL::Vec< long > &vec)

  returns \prod_d vec[d]
- long helib::computeProd (const std::vector< long > &vec)
- NTL::ZZX helib::makeIrredPoly (long p, long d)

  Return a degree-d irreducible polynomial mod p.
- void helib::factorize (std::vector< long > &factors, long N)

  Factoring by trial division, only works for N<2^{60}, only the primes are recorded, not their multiplicity.
- void helib::factorize (std::vector< NTL::ZZ > &factors, const NTL::ZZ &N)
- void helib::factorize (NTL::Vec< NTL::Pair< long, long >> &factors, long N)

  Factoring by trial division, only works for N<2^{60} primes and multiplicities are recorded.
- void helib::pp_factorize (std::vector< long > &factors, long N)

  Prime-power factorization.
- void helib::phiN (long &phiN, std::vector< long > &facts, long N)

  Compute Phi(N) and also factorize N.
- void helib::phiN (NTL::ZZ &phiN, std::vector< NTL::ZZ > &facts, const NTL::ZZ &N)

- long helib::phi_N (long N)

    Compute Phi(N).
- long helib::findGenerators (std::vector< long > &gens, std::vector< long > &ords, long m, long p, const std::vector< long > &candidates=std::vector< long >())
- template<typename zp , typename zz >
  void helib::FindPrimRootT (zp &root, unsigned long e)
- void helib::FindPrimitiveRoot (NTL::zz_p &r, unsigned long e)

    Find e-th root of unity modulo the current modulus.
- void helib::FindPrimitiveRoot (NTL::ZZ_p &r, unsigned long e)
- long helib::mobius (long n)

    Compute mobius function (naive method as n is small).
- NTL::ZZX helib::Cyclotomic (long N)

    Compute cyclotomic polynomial.
- long helib::primroot (long N, long phiN)

    Find a primitive root modulo N.
- long helib::ord (long N, long p)

    Compute the highest power of p that divides N.
- NTL::ZZX helib::RandPoly (long n, const NTL::ZZ &p)
- void helib::MulMod (NTL::ZZX &out, const NTL::ZZX &f, long a, long q, bool abs)
- void helib::balanced_MulMod (NTL::ZZX &out, const NTL::ZZX &f, long a, long q)
- long helib::is_in (long x, int ∗X, long sz)

    Finds whether x is an element of the set X of size sz, Returns -1 it not and the location if true.
- template<class zzvec >
  bool helib::intVecCRT (NTL::vec_ZZ &vp, const NTL::ZZ &p, const zzvec &vq, long q)

    Incremental integer CRT for vectors.
- template bool helib::intVecCRT (NTL::vec_ZZ &, const NTL::ZZ &, const NTL::vec_ZZ &, long)
- template bool helib::intVecCRT (NTL::vec_ZZ &, const NTL::ZZ &, const NTL::vec_long &, long)
- template bool helib::intVecCRT (NTL::vec_ZZ &, const NTL::ZZ &, const NTL::Vec< NTL::zz_p > &, long)
- void helib::ModComp (NTL::ZZX &res, const NTL::ZZX &g, const NTL::ZZX &h, const NTL::ZZX &f)

    Modular composition of polynomials: res = g(h) mod f.
- long helib::polyEvalMod (const NTL::ZZX &poly, long x, long p)

    Evaluates a modular integer polynomial, returns poly(x) mod p.
- void helib::interpolateMod (NTL::ZZX &poly, const NTL::vec_long &x, const NTL::vec_long &y, long p, long e=1)

    Interpolate polynomial such that poly(x[i] mod p)=y[i] (mod p^ e) It is assumed that the points x[i] are all distinct modulo p.
- void helib::seekPastChar (std::istream &str, int cc)

    Advance the input stream beyond white spaces and a single instance of the char cc.
- void helib::buildLinPolyMatrix (NTL::mat_zz_pE &M, long p)
- void helib::buildLinPolyMatrix (NTL::mat_GF2E &M, long p)
- void helib::mul (std::vector< NTL::ZZX > &x, const std::vector< NTL::ZZX > &a, long b)
- void helib::div (std::vector< NTL::ZZX > &x, const std::vector< NTL::ZZX > &a, long b)
- void helib::add (std::vector< NTL::ZZX > &x, const std::vector< NTL::ZZX > &a, const std::vector< NTL↩ ::ZZX > &b)
- void helib::ppsolve (NTL::vec_zz_pE &x, const NTL::mat_zz_pE &A, const NTL::vec_zz_pE &b, long p, long r)

    Prime power solver.
- void helib::ppsolve (NTL::vec_GF2E &x, const NTL::mat_GF2E &A, const NTL::vec_GF2E &b, long p, long r)

    A version for GF2: must have p == 2 and r == 1.
- void helib::ppInvert (NTL::mat_zz_pE &X, const NTL::mat_zz_pE &A, long p, long r)
- void helib::ppInvert (NTL::mat_zz_p &X, const NTL::mat_zz_p &A, long p, long r)

    Compute the inverse mod p^ r of an n x n matrix.
- void helib::buildLinPolyCoeffs (NTL::vec_zz_pE &C, const NTL::vec_zz_pE &L, long p, long r)

Combination of buildLinPolyMatrix and ppsolve.
- void helib::buildLinPolyCoeffs (NTL::vec_GF2E &C, const NTL::vec_GF2E &L, long p, long r)

  A version for GF2: must be called with p == 2 and r == 1.
- void helib::applyLinPoly (NTL::zz_pE &beta, const NTL::vec_zz_pE &C, const NTL::zz_pE &alpha, long p)

  Apply a linearized polynomial with coefficient vector C.
- void helib::applyLinPoly (NTL::GF2E &beta, const NTL::vec_GF2E &C, const NTL::GF2E &alpha, long p)

  A version for GF2: must be called with p == 2 and r == 1.
- std::pair< long, long > helib::rationalApprox (double x, long denomBound=0)
- std::pair< NTL::ZZ, NTL::ZZ > helib::rationalApprox (NTL::xdouble x, NTL::xdouble denomBound=NTL↩ ::xdouble(0.0))
- void helib::rem (NTL::zz_pX &r, const NTL::zz_pX &a, const zz_pXModulus1 &ff)

- void helib::PolyRed (NTL::ZZX &out, const NTL::ZZX &in, const NTL::ZZ &q, bool abs=false)
- void helib::PolyRed (NTL::ZZX &out, const NTL::ZZX &in, long q, bool abs=false)

  Reduce all the coefficients of a polynomial modulo q.
- void helib::vecRed (NTL::Vec< NTL::ZZ > &out, const NTL::Vec< NTL::ZZ > &in, long q, bool abs)
- void helib::vecRed (NTL::Vec< NTL::ZZ > &out, const NTL::Vec< NTL::ZZ > &in, const NTL::ZZ &q, bool abs)

Some enhanced conversion routines

- void helib::convert (NTL::vec_zz_pE &X, const std::vector< NTL::ZZX > &A)
- void helib::convert (NTL::mat_zz_pE &X, const std::vector< std::vector< NTL::ZZX >> &A)
- void helib::convert (std::vector< NTL::ZZX > &X, const NTL::vec_zz_pE &A)
- void helib::convert (std::vector< std::vector< NTL::ZZX >> &X, const NTL::mat_zz_pE &A)
- void helib::convert (NTL::Vec< long > &out, const NTL::ZZX &in)
- void helib::convert (NTL::Vec< long > &out, const NTL::zz_pX &in, bool symmetric=true)
- void helib::convert (NTL::Vec< long > &out, const NTL::GF2X &in)
- void helib::convert (NTL::ZZX &out, const NTL::Vec< long > &in)
- void helib::convert (NTL::GF2X &out, const NTL::Vec< long > &in)

8.77 /HElib/src/OptimizePermutations.cpp File Reference

```
#include <cstdlib>
#include <list>
#include <sstream>
#include <memory>
#include <NTL/vector.h>
#include <helib/NumbTh.h>
#include <helib/EncryptedArray.h>
#include <helib/permutations.h>
#include <helib/apiAttributes.h>
```

Namespaces

- helib

Functions

- void helib::removeDups (std::list< long > &x, bool ∗aux)
- void helib::addOffset (std::list< long > &x, long offset, long n, bool ∗aux, UNUSED bool good=false)
- long helib::reducedCount (const std::list< long > &x, long n, bool ∗aux)
- void helib::buildBenesCostTable (long n, long k, bool good, NTL::Vec< NTL::Vec< long >> &tab)
- std::ostream & helib::operator<< (std::ostream &s, LongNodePtr p)
- BenesMemoEntry helib::optimalBenesAux (long i, long budget, long nlev, const NTL::Vec< NTL::Vec< long >> &costTab, BenesMemoTable &memoTab)
- void helib::optimalBenes (long n, long budget, bool good, long &cost, LongNodePtr &solution)
- void helib::print (std::ostream &s, SplitNodePtr p, bool first)
- std::ostream & helib::operator<< (std::ostream &s, SplitNodePtr p)
- long helib::length (GenNodePtr ptr)
- std::ostream & helib::operator<< (std::ostream &s, GenNodePtr p)
- LowerMemoEntry helib::optimalLower (long order, bool good, long budget, long mid, LowerMemoTable &lowerMemoTable)
- UpperMemoEntry helib::optimalUpperAux (const NTL::Vec< GenDescriptor > &vec, long i, long budget, long mid, UpperMemoTable &upperMemoTable, LowerMemoTable &lowerMemoTable)

8.78 /HElib/src/PAlgebra.cpp File Reference

```
#include <algorithm>
#include <cmath>
#include <helib/PAlgebra.h>
#include <helib/hypercube.h>
#include <helib/timing.h>
#include <NTL/ZZXFactoring.h>
#include <NTL/GF2EXFactoring.h>
#include <NTL/lzz_pEXFactoring.h>
#include <NTL/BasicThreadPool.h>
#include <mutex>
```

Namespaces

- helib

Functions

- template<typename RX >
  bool helib::poly_comp (const RX &a, const RX &b)
- bool helib::less_than (NTL::GF2 a, NTL::GF2 b)
- bool helib::less_than (NTL::zz_p a, NTL::zz_p b)
- bool helib::less_than (const NTL::GF2X &a, const NTL::GF2X &b)
- bool helib::less_than (const NTL::zz_pX &a, const NTL::zz_pX &b)
- bool helib::less_than (const NTL::GF2E &a, const NTL::GF2E &b)
- bool helib::less_than (const NTL::zz_pE &a, const NTL::zz_pE &b)
- bool helib::less_than (const NTL::GF2EX &a, const NTL::GF2EX &b)
- bool helib::less_than (const NTL::zz_pEX &a, const NTL::zz_pEX &b)
- double helib::calcPolyNormBnd (long m)

- bool helib::comparePAlgebra (const PAlgebra &palg, unsigned long m, unsigned long p, UNUSED unsigned long r, const std::vector< long > &gens, const std::vector< long > &ords)
- PAlgebraModBase ∗ helib::buildPAlgebraMod (const PAlgebra &zMStar, long r)

  Builds a table, of type PA_GF2 if p == 2 and r == 1, and PA_zz_p otherwise.
- template<typename T >
  void helib::PAlgebraLift (const NTL::ZZX &phimx, const T &lfactors, T &factors, T &crtc, long r)
- void helib::EDF (NTL::vec_zz_pX &v, const NTL::zz_pX &f, long d)
- NTL::zz_pEX helib::FrobeniusMap (const NTL::zz_pEXModulus &F)
- void helib::InvModpr (NTL::zz_pX &S, const NTL::zz_pX &F, const NTL::zz_pX &G, long p, long r)
- template<> void helib::PAlgebraLift (const NTL::ZZX &phimx, const NTL::vec_zz_pX &lfactors, NTL::vec↩_zz_pX &factors, NTL::vec_zz_pX &crtc, long r)

8.79 /HElib/src/PermNetwork.cpp File Reference

```
#include <NTL/ZZ.h>
#include <helib/Context.h>
#include <helib/Ctxt.h>
#include <helib/permutations.h>
#include <helib/EncryptedArray.h>
```

Namespaces

- helib

Functions

- std::ostream & helib::operator<< (std::ostream &s, const PermNetwork &net)

8.80 /HElib/src/permutations.cpp File Reference

```
#include <helib/permutations.h>
```

Namespaces

- helib

Functions

- template<typename T >
  void helib::applyPermToVec (NTL::Vec< T > &out, const NTL::Vec< T > &in, const Permut &p1)

  Apply a permutation to a std::vector, out[i]=in[p1[i]] (NOT in-place)
- template<typename T >
  void helib::applyPermToVec (std::vector< T > &out, const std::vector< T > &in, const Permut &p1)
- template<typename T >
  void helib::applyPermsToVec (NTL::Vec< T > &out, const NTL::Vec< T > &in, const Permut &p2, const Permut &p1)

  Apply two permutations to a std::vector out[i]=in[p2[p1[i]]] (NOT in-place)
- template<typename T >
  void helib::applyPermsToVec (std::vector< T > &out, const std::vector< T > &in, const Permut &p2, const Permut &p1)
- template void helib::applyPermToVec< long > (NTL::Vec< long > &out, const NTL::Vec< long > &in, const Permut &p1)
- template void helib::applyPermToVec< long > (std::vector< long > &out, const std::vector< long > &in, const Permut &p1)
- template void helib::applyPermToVec< NTL::ZZX > (std::vector< NTL::ZZX > &out, const std::vector< N↩
  TL::ZZX > &in, const Permut &p1)
- template void helib::applyPermsToVec< long > (NTL::Vec< long > &out, const NTL::Vec< long > &in, const Permut &p2, const Permut &p1)
- template void helib::applyPermsToVec< long > (std::vector< long > &out, const std::vector< long > &in, const Permut &p2, const Permut &p1)
- void helib::randomPerm (Permut &perm, long n)

  A random size-n permutation.
- void helib::breakPermTo3 (const HyperCube< long > &pi, long dim, ColPerm &rho1, HyperCube< long > &rho2, ColPerm &rho3)
- void helib::breakPermByDim (std::vector< ColPerm > &out, const Permut &pi, const CubeSignature &sig)

  *Takes a permutation pi over m-dimensional cube C=Z_{n1} x...x Z_{nm} and expresses pi as a product pi = rho_↩
  {2m-1} o ... o rho_2 o rho_1 where each rho_i is a column permutation along one dimension. Specifically for i<m, the permutations rho_i and rho_{2(m-1)-i} permute the i'th dimension.*
- void helib::ComputeOneGenMapping (Permut &genMap, const OneGeneratorTree &T)

  to a single generator tree
- std::ostream & helib::operator<< (std::ostream &s, const ColPerm &p)
- std::ostream & helib::operator<< (std::ostream &s, const SubDimension &sd)
- std::ostream & helib::operator<< (std::ostream &s, const GeneratorTrees &trees)

8.81 /HElib/src/PGFFT.cpp File Reference

```
#include <helib/PGFFT.h>
#include <cassert>
#include <cstdlib>
#include <limits>
```

Namespaces

- helib

Macros

- #define PGFFT_USE_TRUNCATED_BLUE (1)
- #define PGFFT_USE_EXPLICIT_MUL (1)
- #define RESTRICT
- #define PGFFT_FFT_RDUP (4)
- #define fwd_butterfly(xx0, xx1, w)
- #define fwd_butterfly0(xx0, xx1)
- #define inv_butterfly0(xx0, xx1)
- #define inv_butterfly(xx0, xx1, w)
- #define PGFFT_NEW_FFT_THRESH (10)
- #define PGFFT_BRC_THRESH (11)
- #define PGFFT_BRC_Q (5)
- #define PGFFT_STRATEGY_NULL (0)
- #define PGFFT_STRATEGY_POW2 (1)
- #define PGFFT_STRATEGY_BLUE (2)
- #define PGFFT_STRATEGY_TBLUE (3)

Typedefs

- template< class T >
  using helib::aligned_vector = PGFFT::aligned_vector< T >
- typedef complex< double > helib::cmplx_t
- typedef long double helib::ldbl

8.81.1 Macro Definition Documentation

8.81.1.1 fwd_butterfly

```
#define fwd_butterfly(
                xx0,
                xx1,
                w )
```

Value:

```
do \
{ \
   cmplx_t x0_ = xx0; \
   cmplx_t x1_ = xx1; \
   cmplx_t t_  = x0_ -  x1_; \
   xx0 = x0_ + x1_; \
   xx1 = MUL(t_, w); \
}  \
while (0)
```

8.81.1.2 fwd_butterfly0

```
#define fwd_butterfly0(
                xx0,
                xx1 )
```

Value:
```
do   \
{  \
   cmplx_t x0_ = xx0;  \
   cmplx_t x1_ = xx1;  \
   xx0 = x0_ + x1_; \
   xx1 = x0_ - x1_; \
}  \
while (0)
```

8.81.1.3 inv_butterfly

```
#define inv_butterfly(
                xx0,
                xx1,
                w )
```

Value:
```
do  \
{  \
   cmplx_t x0_ = xx0;  \
   cmplx_t x1_ = xx1;  \
   cmplx_t t_ = CMUL(x1_, w);  \
   xx0 = x0_ + t_;  \
   xx1 = x0_ - t_;  \
} while (0)
```

8.81.1.4 inv_butterfly0

```
#define inv_butterfly0(
                xx0,
                xx1 )
```

Value:
```
do   \
{  \
   cmplx_t x0_ = xx0;  \
   cmplx_t x1_ = xx1;  \
   xx0 = x0_ + x1_;  \
   xx1 = x0_ - x1_;  \
} while (0)
```

8.81.1.5 PGFFT_BRC_Q

```
#define PGFFT_BRC_Q (5)
```

8.81.1.6 PGFFT_BRC_THRESH

```
#define PGFFT_BRC_THRESH (11)
```

8.81.1.7 PGFFT_FFT_RDUP

```
#define PGFFT_FFT_RDUP (4)
```

8.81.1.8 PGFFT_NEW_FFT_THRESH

```
#define PGFFT_NEW_FFT_THRESH (10)
```

8.81.1.9 PGFFT_STRATEGY_BLUE

```
#define PGFFT_STRATEGY_BLUE (2)
```

8.81.1.10 PGFFT_STRATEGY_NULL

```
#define PGFFT_STRATEGY_NULL (0)
```

8.81.1.11 PGFFT_STRATEGY_POW2

```
#define PGFFT_STRATEGY_POW2 (1)
```

8.81.1.12 PGFFT_STRATEGY_TBLUE

```
#define PGFFT_STRATEGY_TBLUE (3)
```

8.81.1.13 PGFFT_USE_EXPLICIT_MUL

```
#define PGFFT_USE_EXPLICIT_MUL (1)
```

8.81.1.14 PGFFT_USE_TRUNCATED_BLUE

```
#define PGFFT_USE_TRUNCATED_BLUE (1)
```

8.81.1.15 RESTRICT

```
#define RESTRICT
```

8.82 /HElib/src/polyEval.cpp File Reference

```
#include <helib/Context.h>
#include <helib/polyEval.h>
```

Namespaces

- helib

Functions

- void helib::polyEval (Ctxt &ret, const NTL::Vec< Ctxt > &poly, const Ctxt &x)

    Evaluate an encrypted polynomial on an encrypted input.
- void helib::polyEval (Ctxt &ret, NTL::ZZX poly, const Ctxt &x, long k=0)

    Evaluate a cleartext polynomial on an encrypted input.

8.83 /HElib/src/PolyMod.cpp File Reference

```
#include <helib/PolyMod.h>
#include <helib/exceptions.h>
#include <NTL/ZZX.h>
#include <NTL/ZZ_p.h>
#include <vector>
```

Namespaces

- helib

Functions

- std::istream & helib::operator>> (std::istream &is, PolyMod &poly)
- std::ostream & helib::operator<< (std::ostream &os, const PolyMod &poly)

8.84 /HElib/src/PolyModRing.cpp File Reference

```
#include <helib/PolyModRing.h>
```

Namespaces

- helib

Functions

- std::ostream & helib::operator<< (std::ostream &os, const PolyModRing &ring)

8.85 /HElib/src/powerful.cpp File Reference

```
#include <helib/powerful.h>
```

Namespaces

- helib

Functions

- void helib::computeDivVec (NTL::Vec< long > &divVec, long m, const NTL::Vec< long > &powVec)
- void helib::computeInvVec (NTL::Vec< long > &invVec, const NTL::Vec< long > &divVec, const NTL::Vec< long > &powVec)

8.86 /HElib/src/primeChain.cpp File Reference

handling the chain of moduli

```
#include <climits>
#include <cmath>
#include <algorithm>
#include <helib/primeChain.h>
#include <helib/Context.h>
#include <helib/sample.h>
#include <helib/binio.h>
```

Classes

- struct helib::PrimeGenerator

Namespaces

- helib

Functions

- bool helib::operator> (const ModuliSizes::Entry &a, const ModuliSizes::Entry &b)
- std::ostream & helib::operator<< (std::ostream &s, const ModuliSizes::Entry &e)
- std::istream & helib::operator>> (std::istream &s, ModuliSizes::Entry &e)
- void helib::write (std::ostream &s, const ModuliSizes::Entry &e)
- void helib::read (std::istream &s, ModuliSizes::Entry &e)
- std::ostream & helib::operator<< (std::ostream &s, const ModuliSizes &szs)
- std::istream & helib::operator>> (std::istream &s, ModuliSizes &szs)
- void helib::addSmallPrimes (Context &context, long resolution, long cpSize)

  Add small primes to get target resolution.
- long helib::ctxtPrimeSize (long nBits)
- void helib::addCtxtPrimes (Context &context, long nBits, long targetSize)
- void helib::endBuildModChain (Context &context)
- void helib::buildModChain (Context &context, long nBits, long nDgts=3, bool willBeBootstrappable=false, long skHwt=0, long resolution=3, long bitsInSpecialPrimes=0)

8.86.1 Detailed Description

handling the chain of moduli

8.87 /HElib/src/Ptxt.cpp File Reference

```
#include <random>
#include <helib/Ptxt.h>
#include <helib/apiAttributes.h>
```

Namespaces

- helib

Functions

- template<typename Scheme >
  Scheme::SlotType helib::randomSlot (const Context &context)
- template<> BGV::SlotType helib::randomSlot< BGV > (const Context &context)
- template<> CKKS::SlotType helib::randomSlot< CKKS > (UNUSED const Context &context)

8.88 /HElib/src/randomMatrices.cpp File Reference

implementation of random matrices of various forms build functions, used for testing

```
#include <helib/randomMatrices.h>
```

Namespaces

- helib

Functions

- MatMul1D ∗ helib::buildRandomMatrix (const EncryptedArray &ea, long dim)
- MatMul1D ∗ helib::buildRandomMultiMatrix (const EncryptedArray &ea, long dim)
- BlockMatMul1D ∗ helib::buildRandomBlockMatrix (const EncryptedArray &ea, long dim)
- BlockMatMul1D ∗ helib::buildRandomMultiBlockMatrix (const EncryptedArray &ea, long dim)
- MatMulFull ∗ helib::buildRandomFullMatrix (const EncryptedArray &ea)
- BlockMatMulFull ∗ helib::buildRandomFullBlockMatrix (const EncryptedArray &ea)

8.88.1 Detailed Description

implementation of random matrices of various forms build functions, used for testing

8.89 /HElib/src/recryption.cpp File Reference

```
#include <NTL/BasicThreadPool.h>
#include <helib/recryption.h>
#include <helib/EncryptedArray.h>
#include <helib/EvalMap.h>
#include <helib/powerful.h>
#include <helib/CtPtrs.h>
#include <helib/intraSlot.h>
#include <helib/norms.h>
#include <helib/sample.h>
#include <helib/debugging.h>
#include <helib/fhe_stats.h>
```

Classes

- struct helib::PubKeyHack

Namespaces

- helib

Macros

- #define DROP_BEFORE_THIN_RECRYPT
- #define THIN_RECRYPT_NLEVELS (3)

Functions

- void helib::extractDigitsPacked (Ctxt &ctxt, long botHigh, long r, long ePrime, const std::vector< NTL::ZZX > &unpackSlotEncoding)
- void helib::extractDigitsThin (Ctxt &ctxt, long botHigh, long r, long ePrime)
- void helib::packedRecrypt (const CtPtrs &cPtrs, const std::vector< zzX > &unpackConsts, const Encrypted↩ Array &ea)
- void helib::packedRecrypt (const CtPtrs &array, const std::vector< zzX > &unpackConsts, const Encrypted↩ Array &ea, long belowLvl)
- void helib::packedRecrypt (const CtPtrMat &m, const std::vector< zzX > &unpackConsts, const Encrypted↩ Array &ea, long belowLvl=LONG_MAX)

8.89.1 Macro Definition Documentation

8.89.1.1 DROP_BEFORE_THIN_RECRYPT

```
#define DROP_BEFORE_THIN_RECRYPT
```

8.89.1.2 THIN_RECRYPT_NLEVELS

```
#define THIN_RECRYPT_NLEVELS (3)
```

8.90 /HElib/src/replicate.cpp File Reference

```
#include <helib/replicate.h>
#include <helib/timing.h>
#include <helib/clonedPtr.h>
```

Classes

- class helib::ExplicitReplicator

  An implementation of ReplicateHandler that explicitly returns all the replicated ciphertexts in one big vector.
- class helib::replicate_pa_impl< type >

Namespaces

- helib

Functions

- void helib::replicate (const EncryptedArray &ea, Ctxt &ctx, long pos)

  The value in slot #pos is replicated in all other slots. On an n-slot ciphertext, this algorithm performs O(log n) 1D rotations.
- void helib::replicate0 (const EncryptedArray &ea, Ctxt &ctxt, long pos)

  A lower-level routine. Same as replicate, but assumes all slots are zero except slot #pos.
- void helib::replicateAllOrig (const EncryptedArray &ea, const Ctxt &ctxt, ReplicateHandler ∗handler, RepAux ∗repAuxPtr=nullptr)
- void helib::replicateAll (const EncryptedArray &ea, const Ctxt &ctxt, ReplicateHandler ∗handler, long rec↩Bound=64, RepAuxDim ∗repAuxPtr=nullptr)
- void helib::replicateAll (std::vector< Ctxt > &v, const EncryptedArray &ea, const Ctxt &ctxt, long rec↩Bound=64, RepAuxDim ∗repAuxPtr=nullptr)
- void helib::replicate (const EncryptedArray &ea, PlaintextArray &pa, long i)

8.91 /HElib/src/sample.cpp File Reference

```
#include <vector>
#include <NTL/ZZX.h>
#include <NTL/ZZ_pX.h>
#include <NTL/BasicThreadPool.h>
#include <helib/NumbTh.h>
#include <helib/Context.h>
#include <helib/sample.h>
#include <helib/norms.h>
#include <helib/apiAttributes.h>
#include <helib/powerful.h>
```

Namespaces

- helib

Functions

- void helib::sampleHWt (zzX &poly, long n, long Hwt=100)

  Sample a degree-(n-1) poly as above, with only Hwt nonzero coefficients.
- void helib::sampleHWt (NTL::ZZX &poly, long n, long Hwt=100)
- void helib::sampleSmall (zzX &poly, long n, double prob=0.5)
- void helib::sampleSmall (NTL::ZZX &poly, long n, double prob=0.5)
- void helib::sampleGaussian (std::vector< double > &dvec, long n, double stdev)

  Choose a vector of continuous Gaussians.
- void helib::sampleGaussian (zzX &poly, long n, double stdev)

  Sample polynomials with Gaussian coefficients.
- void helib::sampleGaussian (NTL::ZZX &poly, long n, double stdev)
- void helib::sampleUniform (zzX &poly, long n, long B=100)

  Sample a degree-(n-1) ZZX, with coefficients uniform in [-B,B].
- void helib::sampleUniform (NTL::ZZX &poly, long n, const NTL::ZZ &B=NTL::ZZ(100L))
- double helib::sampleHWt (zzX &poly, const Context &context, long Hwt=100)
- double helib::sampleHWtBoundedEffectiveBound (const Context &context, long Hwt=100)
- double helib::sampleHWtBounded (zzX &poly, const Context &context, long Hwt=100)

- double helib::sampleSmall (zzX &poly, const Context &context)
- double helib::sampleSmallBounded (zzX &poly, const Context &context)
- double helib::sampleGaussian (zzX &poly, const Context &context, double stdev)
- double helib::sampleGaussianBounded (zzX &poly, const Context &context, double stdev)
- double helib::sampleUniform (zzX &poly, const Context &context, long B=100)
- NTL::xdouble helib::sampleUniform (NTL::ZZX &poly, const Context &context, const NTL::ZZ &B=NTL::↩ ZZ(100L))
- double helib::boundRoundingNoise (UNUSED long m, long phim, long p2r, double epsilon)
- double helib::boundFreshNoise (long m, long phim, double sigma, double epsilon=9e-13)

8.92 /HElib/src/tableLookup.cpp File Reference

Code for homomorphic table lookup and fixed-point functions.

```
#include <limits>
#include <cmath>
#include <cstdlib>
#include <stdexcept>
#include <NTL/BasicThreadPool.h>
#include <helib/intraSlot.h>
#include <helib/tableLookup.h>
```

Namespaces

- helib

Functions

- void helib::computeAllProducts (CtPtrs &products, const CtPtrs &array, std::vector< zzX > *unpackSlot↩ Encoding=nullptr)
- void helib::tableLookup (Ctxt &out, const std::vector< zzX > &table, const CtPtrs &idx, std::vector< zzX > *unpackSlotEncoding=nullptr)
- void helib::tableWriteIn (const CtPtrs &table, const CtPtrs &idx, std::vector< zzX > *unpackSlot↩ Encoding=nullptr)
- void helib::buildLookupTable (std::vector< zzX > &T, std::function< double(double)> f, long nbits_in, long scale_in, long sign_in, long nbits_out, long scale_out, long sign_out, const EncryptedArray &ea)

  Built a table-lookup for a function in fixed-point representation.

8.92.1 Detailed Description

Code for homomorphic table lookup and fixed-point functions.

8.93 /HElib/src/Test_approxNums.cpp File Reference

```
#include <NTL/ZZ.h>
#include <algorithm>
#include <complex>
#include <helib/norms.h>
#include <helib/helib.h>
#include <helib/debugging.h>
#include <helib/ArgMap.h>
```

Functions

- double calcMaxDiff (const vector< cx_double > &v1, const vector< cx_double > &v2)
- double calcMaxRelDiff (const vector< cx_double > &v1, const vector< cx_double > &v2)
- bool cx_equals (const vector< cx_double > &v1, const vector< cx_double > &v2, double epsilon)
- void testBasicArith (const PubKey &publicKey, const SecKey &secretKey, const EncryptedArrayCx &ea, double epsilon)
- void testComplexArith (const PubKey &publicKey, const SecKey &secretKey, const EncryptedArrayCx &ea, double epsilon)
- void testRotsNShifts (const PubKey &publicKey, const SecKey &secretKey, const EncryptedArrayCx &ea, double epsilon)
- void debugCompare (const EncryptedArrayCx &ea, const SecKey &sk, vector< cx_double > &p, const Ctxt &c, double epsilon)
- void negateVec (vector< cx_double > &p1)
- void add (vector< cx_double > &to, const vector< cx_double > &from)
- void sub (vector< cx_double > &to, const vector< cx_double > &from)
- void mul (vector< cx_double > &to, const vector< cx_double > &from)
- void rotate (vector< cx_double > &p, long amt)
- void testGeneralOps (const PubKey &publicKey, const SecKey &secretKey, const EncryptedArrayCx &ea, double epsilon, long nRounds)
- int main (int argc, char *argv[ ])

Variables

- bool verbose =false

8.93.1 Function Documentation

8.93.1.1 add()

```
void add (
            vector< cx_double > & to,
            const vector< cx_double > & from )
```

8.93.1.2 calcMaxDiff()

```
double calcMaxDiff (
            const vector< cx_double > & v1,
            const vector< cx_double > & v2 )
```

8.93.1.3 calcMaxRelDiff()

```
double calcMaxRelDiff (
            const vector< cx_double > & v1,
            const vector< cx_double > & v2 )
```

8.93.1.4 cx_equals()

```
bool cx_equals (
            const vector< cx_double > & v1,
            const vector< cx_double > & v2,
            double epsilon )  [inline]
```

8.93.1.5 debugCompare()

```
void debugCompare (
            const EncryptedArrayCx & ea,
            const SecKey & sk,
            vector< cx_double > & p,
            const Ctxt & c,
            double epsilon )
```

8.93.1.6 main()

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

8.93.1.7 mul()

```
void mul (
            vector< cx_double > & to,
            const vector< cx_double > & from )
```

8.93.1.8 negateVec()

```
void negateVec (
            vector< cx_double > & p1 )
```

8.93.1.9 rotate()

```
void rotate (
            vector< cx_double > & p,
            long amt )
```

8.93.1.10 sub()

```
void sub (
            vector< cx_double > & to,
            const vector< cx_double > & from )
```

8.93.1.11 testBasicArith()

```
void testBasicArith (
            const PubKey & publicKey,
            const SecKey & secretKey,
            const EncryptedArrayCx & ea,
            double epsilon )
```

8.93.1.12 testComplexArith()

```
void testComplexArith (
            const PubKey & publicKey,
            const SecKey & secretKey,
            const EncryptedArrayCx & ea,
            double epsilon )
```

8.93.1.13 testGeneralOps()

```
void testGeneralOps (
            const PubKey & publicKey,
            const SecKey & secretKey,
            const EncryptedArrayCx & ea,
            double epsilon,
            long nRounds )
```

8.93.1.14 testRotsNShifts()

```
void testRotsNShifts (
            const PubKey & publicKey,
            const SecKey & secretKey,
            const EncryptedArrayCx & ea,
            double epsilon )
```

8.93.2 Variable Documentation

8.93.2.1 verbose

```
bool verbose =false
```

8.94 /HElib/src/Test_Bin_IO.cpp File Reference

```
#include <cassert>
#include <cstring>
#include <fstream>
#include <utility>
#include <unistd.h>
#include <NTL/ZZX.h>
#include <NTL/vector.h>
#include <helib/helib.h>
#include <helib/ArgMap.h>
#include <helib/debugging.h>
```

Functions

- bool isLittleEndian ()
- void cleanupFiles (const char *file)
- template<class... Files>
  void cleanupFiles (const char *file, Files... files)
- long compareFiles (string filename1, string filename2)
- int main (int argc, char *argv[ ])

8.94.1 Function Documentation

8.94.1.1 cleanupFiles() [1/2]

```
void cleanupFiles (
            const char * file )
```

8.94.1.2 cleanupFiles() [2/2]

```
template<class... Files>
void cleanupFiles (
            const char * file,
            Files... files )
```

8.94.1.3 compareFiles()

```
long compareFiles (
            string filename1,
            string filename2 )
```

8.94.1.4 isLittleEndian()

```
bool isLittleEndian ( )
```

8.94.1.5 main()

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

8.95 /HElib/src/Test_binaryArith.cpp File Reference

```
#include <iostream>
#include <cassert>
#include <fstream>
#include <vector>
#include <cmath>
#include <algorithm>
#include <NTL/BasicThreadPool.h>
#include <helib/helib.h>
#include <helib/intraSlot.h>
#include <helib/binaryArith.h>
#include <helib/ArgMap.h>
```

Functions

- void test15for4 (SecKey &secKey)
- void testProduct (SecKey &secKey, long bitSize1, long bitSize2, long outSize, bool bootstrap=false)
- void testAdd (SecKey &secKey, long bitSize1, long bitSize2, long outSize, bool bootstrap=false)
- int main (int argc, char *argv[ ])

8.95.1 Function Documentation

8.95.1.1 main()

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

8.95.1.2 test15for4()

```
void test15for4 (
            SecKey & secKey )
```

8.95.1.3 testAdd()

```
void testAdd (
            SecKey & secKey,
            long bitSize1,
            long bitSize2,
            long outSize,
            bool bootstrap = false )
```

8.95.1.4 testProduct()

```
void testProduct (
            SecKey & secKey,
            long bitSize1,
            long bitSize2,
            long outSize,
            bool bootstrap = false )
```

8.96 /HElib/src/Test_binaryCompare.cpp File Reference

```
#include <iostream>
#include <cassert>
#include <fstream>
#include <vector>
#include <cmath>
#include <algorithm>
#include <NTL/BasicThreadPool.h>
#include <helib/helib.h>
#include <helib/intraSlot.h>
#include <helib/binaryArith.h>
#include <helib/binaryCompare.h>
#include <helib/ArgMap.h>
```

Functions

- void testCompare (SecKey &secKey, long bitSize, bool bootstrap=false)
- int main (int argc, char ∗argv[ ])

8.96.1 Function Documentation

8.96.1.1 main()

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

8.96.1.2 testCompare()

```
void testCompare (
            SecKey & secKey,
            long bitSize,
            bool bootstrap = false )
```

8.97 /HElib/src/Test_bootstrapping.cpp File Reference

```
#include <NTL/ZZ.h>
#include <NTL/fileio.h>
#include <NTL/BasicThreadPool.h>
#include <cassert>
#include <helib/EncryptedArray.h>
#include <helib/EvalMap.h>
#include <helib/powerful.h>
#include <helib/matmul.h>
#include <helib/ArgMap.h>
#include <helib/debugging.h>
```

Macros

- #define num_mValues (sizeof(mValues)/(14∗sizeof(long)))
- #define OUTER_REP (1)
- #define INNER_REP (1)

Functions

- void TestIt (long idx, long p, long r, long L, long c, long skHwt, int build_cache=0)
- int main (int argc, char ∗argv[ ])

8.97.1 Macro Definition Documentation

8.97.1.1 INNER_REP

```
#define INNER_REP (1)
```

8.97.1.2 num_mValues

```
#define num_mValues (sizeof(mValues)/(14*sizeof(long)))
```

8.97.1.3 OUTER_REP

```
#define OUTER_REP (1)
```

8.97.2 Function Documentation

8.97.2.1 main()

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

8.97.2.2 TestIt()

```
void TestIt (
            long idx,
            long p,
            long r,
            long L,
            long c,
            long skHwt,
            int build_cache = 0 )
```

8.98 /HElib/src/Test_EaCx.cpp File Reference

```
#include <NTL/ZZ.h>
#include <cassert>
#include <helib/norms.h>
#include <helib/EncryptedArray.h>
#include <helib/ArgMap.h>
```

Functions

- int main (int argc, char ∗argv[ ])

Variables

- bool noPrint = true

8.98.1 Function Documentation

8.98.1.1 main()

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

8.98.2 Variable Documentation

8.98.2.1 noPrint

```
bool noPrint = true
```

8.99 /HElib/src/Test_EvalMap.cpp File Reference

```
#include <NTL/BasicThreadPool.h>
#include <cassert>
#include <helib/EvalMap.h>
#include <helib/hypercube.h>
#include <helib/powerful.h>
#include <helib/ArgMap.h>
```

Namespaces

- std
- NTL

Functions

- void TestIt (long p, long r, long c, long _k, long L, Vec< long > &mvec, Vec< long > &gens, Vec< long > &ords, long useCache)
- int main (int argc, char *argv[ ])

8.99.1 Function Documentation

8.99.1.1 main()

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

8.99.1.2 TestIt()

```
void TestIt (
            long p,
            long r,
            long c,
            long _k,
            long L,
            Vec< long > & mvec,
            Vec< long > & gens,
            Vec< long > & ords,
            long useCache )
```

8.100 /HElib/src/Test_extractDigits.cpp File Reference

```
#include <NTL/ZZ.h>
#include <helib/EncryptedArray.h>
#include <helib/polyEval.h>
#include <helib/debugging.h>
#include <helib/ArgMap.h>
```

Functions

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

8.100.1 Function Documentation

8.100.1.1 main()

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

8.101 /HElib/src/Test_fatboot.cpp File Reference

```
#include <NTL/ZZ.h>
#include <NTL/fileio.h>
#include <NTL/BasicThreadPool.h>
#include <cassert>
#include <helib/EncryptedArray.h>
#include <helib/EvalMap.h>
#include <helib/powerful.h>
#include <helib/matmul.h>
#include <helib/debugging.h>
#include <helib/fhe_stats.h>
#include <helib/ArgMap.h>
```

Macros

- #define OUTER_REP (1)
- #define INNER_REP (1)

Functions

- void TestIt (long p, long r, long L, long c, long skHwt, int build_cache=0)
- int main (int argc, char *argv[ ])

Variables

- long printFlag

8.101.1 Macro Definition Documentation

8.101.1.1 INNER_REP

```
#define INNER_REP (1)
```

8.101.1.2 OUTER_REP

```
#define OUTER_REP (1)
```

8.101.2 Function Documentation

8.101.2.1 main()

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

8.101.2.2 TestIt()

```
void TestIt (
            long p,
            long r,
            long L,
            long c,
            long skHwt,
            int build_cache = 0 )
```

8.101.3 Variable Documentation

8.101.3.1 printFlag

```
long printFlag
```

8.102 /HElib/src/Test_General.cpp File Reference

```
#include <NTL/ZZ.h>
#include <NTL/BasicThreadPool.h>
#include <helib/helib.h>
#include <NTL/lzz_pXFactoring.h>
#include <cassert>
#include <cstdio>
#include <helib/ArgMap.h>
#include <helib/fhe_stats.h>
```

Macros

- #define debugCompare(ea, sk, p, c)

Functions

- void TestIt (long R, long p, long r, long d, long c, long k, long w, long L, long m, const Vec< long > &gens, const Vec< long > &ords)
- int main (int argc, char **argv)

8.102.1 Macro Definition Documentation

8.102.1.1 debugCompare

```
#define debugCompare(
            ea,
            sk,
            p,
            c )
```

8.102.2 Function Documentation

8.102.2.1 main()

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

8.102.2.2 TestIt()

```
void TestIt (
            long R,
            long p,
            long r,
            long d,
            long c,
            long k,
            long w,
            long L,
            long m,
            const Vec< long > & gens,
            const Vec< long > & ords )
```

8.103 /HElib/src/Test_intraSlot.cpp File Reference

```
#include <helib/intraSlot.h>
#include <helib/ArgMap.h>
```

Functions

- int main (int argc, char **argv)

Variables

- bool verbose = false

8.103.1 Function Documentation

8.103.1.1 main()

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

8.103.2 Variable Documentation

8.103.2.1 verbose

```
bool verbose = false
```

8.104 /HElib/src/Test_IO.cpp File Reference

```
#include <cassert>
#include <fstream>
#include <unistd.h>
#include <NTL/ZZX.h>
#include <NTL/vector.h>
#include <helib/helib.h>
#include <helib/ArgMap.h>
```

Macros

- #define N_TESTS 3

Functions

- void checkCiphertext (const Ctxt &ctxt, const ZZX &ptxt, const SecKey &sk)
- int main (int argc, char *argv[ ])

8.104.1 Macro Definition Documentation

8.104.1.1 N_TESTS

```
#define N_TESTS 3
```

8.104.2 Function Documentation

8.104.2.1 checkCiphertext()

```
void checkCiphertext (
            const Ctxt & ctxt,
            const ZZX & ptxt,
            const SecKey & sk )
```

8.104.2.2 main()

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

8.105 /HElib/src/Test_matmul.cpp File Reference

```
#include <helib/matmul.h>
#include <NTL/BasicThreadPool.h>
#include <helib/fhe_stats.h>
#include <helib/randomMatrices.h>
#include <helib/ArgMap.h>
```

Functions

- template<class Matrix >
  bool DoTest (const Matrix &mat, const EncryptedArray &ea, const SecKey &secretKey, bool minimal, bool verbose)
- void TestIt (Context &context, long dim, bool verbose, long full, long block)
- int main (int argc, char *argv[ ])

Variables

- int ks_strategy = 0

8.105.1 Function Documentation

8.105.1.1 DoTest()

```
template<class Matrix >
bool DoTest (
            const Matrix & mat,
            const EncryptedArray & ea,
            const SecKey & secretKey,
            bool minimal,
            bool verbose )
```

8.105.1.2 main()

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

8.105.1.3 TestIt()

```
void TestIt (
            Context & context,
            long dim,
            bool verbose,
            long full,
            long block )
```

8.105.2 Variable Documentation

8.105.2.1 ks_strategy

```
int ks_strategy = 0
```

8.106 /HElib/src/Test_PAlgebra.cpp File Reference

```
#include <cassert>
#include <string>
#include <sstream>
#include <NTL/ZZ.h>
#include <helib/NumbTh.h>
#include <helib/Context.h>
#include <helib/ArgMap.h>
```

Functions

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

8.106.1 Function Documentation

8.106.1.1 main()

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

8.107 /HElib/src/Test_Permutations.cpp File Reference

```
#include <NTL/ZZ.h>
#include <helib/NumbTh.h>
#include <helib/timing.h>
#include <helib/permutations.h>
#include <helib/EncryptedArray.h>
#include <helib/ArgMap.h>
```

Functions

- void testCtxt (long m, long p, long widthBound=0, long L=0, long r=1)
- void testCube (Vec< GenDescriptor > &vec, long widthBound)
- int main (int argc, char ∗argv[ ])

8.107.1 Function Documentation

8.107.1.1 main()

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

8.107.1.2 testCtxt()

```
void testCtxt (
            long m,
            long p,
            long widthBound = 0,
            long L = 0,
            long r = 1 )
```

8.107.1.3 testCube()

```
void testCube (
            Vec< GenDescriptor > & vec,
            long widthBound )
```

8.108 /HElib/src/Test_PGFFT.cpp File Reference

```
#include <helib/PGFFT.h>
#include <iostream>
#include <cstdlib>
#include <ctime>
#include <algorithm>
#include <cmath>
#include <cstddef>
#include <cstdint>
#include <stdexcept>
#include <limits>
```

Namespaces

- Fft

Typedefs

- typedef long double ldbl
- typedef std::complex< ldbl > lcx
- typedef complex< double > cmplx_t

Functions

- void Fft::transform (std::vector< lcx > &vec)
- void Fft::inverseTransform (std::vector< lcx > &vec)
- void Fft::transformRadix2 (std::vector< lcx > &vec)
- void Fft::transformBluestein (std::vector< lcx > &vec)
- void Fft::convolve (const std::vector< lcx > &vecx, const std::vector< lcx > &vecy, std::vector< lcx > &vecout)
- int main ()

8.108.1 Typedef Documentation

8.108.1.1 cmplx_t

```
typedef complex<double> cmplx_t
```

8.108.1.2 lcx

```
typedef std::complex<ldbl> lcx
```

8.108.1.3 ldbl

```
typedef long double ldbl
```

8.108.2 Function Documentation

8.108.2.1 main()

```
int main ( )
```

8.109 /HElib/src/Test_PolyEval.cpp File Reference

```
#include <NTL/ZZ.h>
#include <helib/polyEval.h>
#include <helib/EncryptedArray.h>
#include <helib/ArgMap.h>
#include <helib/debugging.h>
```

Functions

- bool testEncrypted (long d, const EncryptedArray &ea, const SecKey &secretKey)
- void testIt (long d, long k, long p, long r, long m, long L, bool isMonic=false)
- int main (int argc, char ∗argv[ ])

8.109.1 Function Documentation

8.109.1.1 main()

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

8.109.1.2 testEncrypted()

```
bool testEncrypted (
            long d,
            const EncryptedArray & ea,
            const SecKey & secretKey )
```

8.109.1.3 testIt()

```
void testIt (
            long d,
            long k,
            long p,
            long r,
            long m,
            long L,
            bool isMonic = false )
```

8.110 /HElib/src/Test_Powerful.cpp File Reference

```
#include <helib/hypercube.h>
#include <helib/powerful.h>
#include <helib/Context.h>
#include <helib/ArgMap.h>
```

Functions

- void testSimpleConversion (const Vec< long > &mvec)
- void testHighLvlConversion (const Context &context, const Vec< long > &mvec)
- int main (int argc, char *argv[ ])

8.110.1 Function Documentation

8.110.1.1 main()

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

8.110.1.2 testHighLvlConversion()

```
void testHighLvlConversion (
            const Context & context,
            const Vec< long > & mvec )
```

8.110.1.3 testSimpleConversion()

```
void testSimpleConversion (
            const Vec< long > & mvec )
```

8.111 /HElib/src/Test_PtrVector.cpp File Reference

```
#include <cassert>
#include <iostream>
#include <NTL/tools.h>
#include <helib/NumbTh.h>
#include <helib/PtrVector.h>
#include <helib/PtrMatrix.h>
```

Classes

- class MyClass

Typedefs

- typedef PtrVector< MyClass > MyPtrVec
- typedef PtrVector_VecT< MyClass > MyPtrVec_Vec
- typedef PtrVector_VecPt< MyClass > MyPtrVec_VecPt
- typedef PtrVector_vectorT< MyClass > MyPtrVec_vector
- typedef PtrVector_vectorPt< MyClass > MyPtrVec_vectorPt
- typedef PtrVector_slice< MyClass > MyPtrVec_slice
- typedef PtrMatrix< MyClass > MyPtrMat
- typedef PtrMatrix_Vec< MyClass > MyPtrMat_Vec
- typedef PtrMatrix_ptVec< MyClass > MyPtrMat_ptVec
- typedef PtrMatrix_vector< MyClass > MyPtrMat_vector
- typedef PtrMatrix_ptvector< MyClass > MyPtrMat_ptvector

Functions

- template<typename T2 >
  bool compPointers (const MyPtrVec &a, T2 &b)
- void test1 (MyClass array[ ], int length, const MyPtrVec &ptrs)
- void test2 (MyClass ∗array[ ], int length, const MyPtrVec &ptrs)
- void printPtrVector (const MyPtrVec &ptrs)
- void test3 (MyPtrVec &ptrs)
- template<typename T >
  void test4 (const MyPtrMat &mat, const T &array)
- template<typename T >
  void test5 (const MyPtrMat &mat, const T &array)
- int main ()

Variables

- bool verbose = false

8.111.1 Typedef Documentation

8.111.1.1 MyPtrMat

```
typedef PtrMatrix<MyClass> MyPtrMat
```

8.111.1.2 MyPtrMat_ptVec

```
typedef PtrMatrix_ptVec<MyClass> MyPtrMat_ptVec
```

8.111.1.3 MyPtrMat_ptvector

```
typedef PtrMatrix_ptvector<MyClass> MyPtrMat_ptvector
```

8.111.1.4 MyPtrMat_Vec

```
typedef PtrMatrix_Vec<MyClass> MyPtrMat_Vec
```

8.111.1.5 MyPtrMat_vector

```
typedef PtrMatrix_vector<MyClass> MyPtrMat_vector
```

8.111.1.6 MyPtrVec

```
typedef PtrVector<MyClass> MyPtrVec
```

8.111.1.7 MyPtrVec_slice

```
typedef PtrVector_slice<MyClass> MyPtrVec_slice
```

8.111.1.8 MyPtrVec_Vec

```
typedef PtrVector_VecT<MyClass> MyPtrVec_Vec
```

8.111.1.9 MyPtrVec_VecPt

```
typedef PtrVector_VecPt<MyClass> MyPtrVec_VecPt
```

8.111.1.10 MyPtrVec_vector

```
typedef PtrVector_vectorT<MyClass> MyPtrVec_vector
```

8.111.1.11 MyPtrVec_vectorPt

```
typedef PtrVector_vectorPt<MyClass> MyPtrVec_vectorPt
```

8.111.2 Function Documentation

8.111.2.1 compPointers()

```
template<typename T2 >
bool compPointers (
            const MyPtrVec & a,
            T2 & b )
```

8.111.2.2 main()

```
int main ( )
```

8.111.2.3 printPtrVector()

```
void printPtrVector (
            const MyPtrVec & ptrs )
```

8.111.2.4 test1()

```
void test1 (
            MyClass array[],
            int length,
            const MyPtrVec & ptrs )
```

8.111.2.5 test2()

```
void test2 (
            MyClass * array[],
            int length,
            const MyPtrVec & ptrs )
```

8.111.2.6 test3()

```
void test3 (
            MyPtrVec & ptrs )
```

8.111.2.7 test4()

```
template<typename T >
void test4 (
            const MyPtrMat & mat,
            const T & array )
```

8.111.2.8 test5()

```
template<typename T >
void test5 (
            const MyPtrMat & mat,
            const T & array )
```

8.111.3 Variable Documentation

8.111.3.1 verbose

```
bool verbose = false
```

8.112 /HElib/src/Test_Replicate.cpp File Reference

```
#include <cassert>
#include <NTL/lzz_pXFactoring.h>
#include <helib/helib.h>
#include <helib/replicate.h>
#include <helib/ArgMap.h>
```

Classes

- class StopReplicate
- class ReplicateTester

Functions

- void TestIt (long m, long p, long r, long d, long L, long bnd, long B)
- int main (int argc, char *argv[ ])

8.112.1 Function Documentation

8.112.1.1 main()

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

8.112.1.2 TestIt()

```
void TestIt (
            long m,
            long p,
            long r,
            long d,
            long L,
            long bnd,
            long B )
```

8.113 /HElib/src/Test_tableLookup.cpp File Reference

```
#include <iostream>
#include <cassert>
#include <NTL/BasicThreadPool.h>
#include <helib/intraSlot.h>
#include <helib/tableLookup.h>
#include <helib/ArgMap.h>
```

Functions

- void testLookup (const SecKey &sKey, long insize, long outsize)
- void testWritein (const SecKey &sKey, long insize, long nTests)
- int main (int argc, char ∗argv[ ])

8.113.1 Function Documentation

8.113.1.1 main()

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

8.113.1.2 testLookup()

```
void testLookup (
        const SecKey & sKey,
        long insize,
        long outsize )
```

8.113.1.3 testWritein()

```
void testWritein (
        const SecKey & sKey,
        long insize,
        long nTests )
```

8.114 /HElib/src/Test_thinboot.cpp File Reference

```
#include <NTL/BasicThreadPool.h>
#include <helib/helib.h>
#include <helib/matmul.h>
#include <helib/debugging.h>
#include <helib/fhe_stats.h>
#include <helib/ArgMap.h>
#include <algorithm>
#include <cmath>
#include <string>
```

Functions

- void TestIt (long p, long r, long L, long c, long skHwt, int build_cache=0)
- int main (int argc, char *argv[ ])

8.114.1 Function Documentation

8.114.1.1 main()

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

8.114.1.2 TestIt()

```
void TestIt (
            long p,
            long r,
            long L,
            long c,
            long skHwt,
            int build_cache = 0 )
```

8.115 /HElib/src/Test_ThinBootstrapping.cpp File Reference

```
#include <NTL/BasicThreadPool.h>
#include <cassert>
#include <helib/helib.h>
#include <helib/matmul.h>
#include <helib/debugging.h>
#include <helib/ArgMap.h>
```

Macros

- #define num_mValues (sizeof(mValues)/(14*sizeof(long)))
- #define OUTER_REP (1)

Functions

- void TestIt (long idx, long p, long r, long L, long c, long skHwt, int build_cache=0)
- int main (int argc, char *argv[ ])

8.115.1 Macro Definition Documentation

8.115.1.1 num_mValues

```
#define num_mValues (sizeof(mValues)/(14*sizeof(long)))
```

8.115.1.2 OUTER_REP

```
#define OUTER_REP (1)
```

8.115.2 Function Documentation

8.115.2.1 main()

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

8.115.2.2 TestIt()

```
void TestIt (
            long idx,
            long p,
            long r,
            long L,
            long c,
            long skHwt,
            int build_cache = 0 )
```

8.116 /HElib/src/Test_ThinEvalMap.cpp File Reference

```
#include <cassert>
#include <helib/helib.h>
#include <helib/EvalMap.h>
#include <NTL/BasicThreadPool.h>
#include <helib/ArgMap.h>
```

Functions

- void TestIt (long p, long r, long c, long _k, long w, long L, Vec< long > &mvec, Vec< long > &gens, Vec< long > &ords, long useCache)
- int main (int argc, char ∗argv[ ])

8.116.1 Function Documentation

8.116.1.1 main()

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

8.116.1.2 TestIt()

```
void TestIt (
            long p,
            long r,
            long c,
            long _k,
            long w,
            long L,
            Vec< long > & mvec,
            Vec< long > & gens,
            Vec< long > & ords,
            long useCache )
```

8.117 /HElib/src/Test_Timing.cpp File Reference

```
#include <cassert>
#include <cstdio>
#include <memory>
#include <NTL/ZZ.h>
#include <NTL/BasicThreadPool.h>
#include <helib/helib.h>
#include <helib/matmul.h>
#include <helib/replicate.h>
#include <helib/permutations.h>
#include <helib/ArgMap.h>
#include <helib/debugging.h>
#include <helib/randomMatrices.h>
```

Classes

- class LowLvlTimingData
- class HighLvlTimingData
- class OtherTimingData
- class TimingData
- class ReplicateDummy

Macros

- #define numTests 11

Functions

- void timeInit (long m, long p, long r, long d, long L, long nTests)
- long rotationAmount (const EncryptedArray &ea, const PubKey &publicKey, bool onlyWithMatrix)
- void timeOps (const EncryptedArray &ea, const PubKey &publicKey, Ctxt &ret, const vector< Ctxt > &c, ZZX &p, long nTests, LowLvlTimingData &td)
- void timeHighLvl (const EncryptedArray &ea, const PubKey &publicKey, Ctxt &ret, const vector< Ctxt > &c, GeneratorTrees &trees, long nTests, HighLvlTimingData &td)
- void TimeIt (long m, long p, TimingData &data, bool high=false)
- void printTimeData (TimingData &td)
- int main (int argc, char *argv[ ])

8.117.1 Macro Definition Documentation

8.117.1.1 numTests

```
#define numTests 11
```

8.117.2 Function Documentation

8.117.2.1 main()

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

8.117.2.2 printTimeData()

```
void printTimeData (
            TimingData & td )
```

8.117.2.3 rotationAmount()

```
long rotationAmount (
            const EncryptedArray & ea,
            const PubKey & publicKey,
            bool onlyWithMatrix )
```

8.117.2.4 timeHighLvl()

```
void timeHighLvl (
            const EncryptedArray & ea,
            const PubKey & publicKey,
            Ctxt & ret,
            const vector< Ctxt > & c,
            GeneratorTrees & trees,
            long nTests,
            HighLvlTimingData & td )
```

8.117.2.5 timeInit()

```
void timeInit (
            long m,
            long p,
            long r,
            long d,
            long L,
            long nTests )
```

8.117.2.6 TimeIt()

```
void TimeIt (
            long m,
            long p,
            TimingData & data,
            bool high = false )
```

cannot test high-level routines at level <8

8.117.2.7 timeOps()

```
void timeOps (
            const EncryptedArray & ea,
            const PubKey & publicKey,
            Ctxt & ret,
            const vector< Ctxt > & c,
            ZZX & p,
            long nTests,
            LowLvlTimingData & td )
```

8.118 /HElib/src/timing.cpp File Reference

```
#include <algorithm>
#include <utility>
#include <cstring>
#include <ctime>
#include <helib/timing.h>
```

Namespaces

- helib

Functions

- unsigned long helib::GetTimerClock ()
- bool helib::timer_compare (const FHEtimer ∗a, const FHEtimer ∗b)
- void helib::registerTimer (FHEtimer ∗timer)
- void helib::resetAllTimers ()
- void helib::printAllTimers (std::ostream &str=std::cerr)

  Print the value of all timers to stream.
- const FHEtimer ∗ helib::getTimerByName (const char ∗name)
- bool helib::printNamedTimer (std::ostream &str, const char ∗name)

Variables

- const unsigned long helib::CLOCK_SCALE = (unsigned long)CLOCKS_PER_SEC

8.119 /HElib/src/zzX.cpp File Reference

```
#include <mutex>
#include <map>
#include <helib/PAlgebra.h>
#include <helib/timing.h>
#include <helib/zzX.h>
```

Namespaces

- helib

Functions

- void helib::MulMod (zzX &res, const zzX &a, const zzX &b, const PAlgebra &palg)
- void helib::add (zzX &res, const zzX &a, const zzX &b)
- void helib::mul (zzX &res, const zzX &a, long b)
- void helib::div (zzX &res, const zzX &a, long b)
- void helib::normalize (zzX &f)
- const NTL::zz_pXModulus & helib::getPhimXMod (const PAlgebra &palg)
- void helib::reduceModPhimX (zzX &poly, const PAlgebra &palg)
- zzX helib::balanced_zzX (const NTL::zz_pX &f)
- zzX helib::balanced_zzX (const NTL::GF2X &f)

8.119.1 Detailed Description

- manipulating polynomials with single-precision coefficient It is assumed that the result is also single-precision