

# root

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Name	GNN
Version	2.0
Description	Generalized Neural Network Bundle
License	<a href="#">See LICENSE.TXT</a>
Copyright	Copyright (C) 2020 HPCC Systems
Authors	HPCC Systems
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# GNNI

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## DESCRIPTIONS

### **GNNI** GNNI

	GNNI
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Generalized Neural Network Interface

Provides a generalized ECL interface to Keras over Tensorflow. It supports the Keras Functional API as well as the Sequential API.

The Functional style allows models to be defined as a Directed Acyclic Graph (DAG), allowing branching and merging among the layers. It is required for models that have multiple inputs or outputs. For an annotated example using the Functional model with multiple inputs and outputs, see `Test/FuncModelTest.ecl`

The Sequential stle is a bit simpler, but requires a strict sequence of layers, each one feeding into the next. For an annotated example using the Sequential model, see `Test/ClassicTest.ecl`

## THEORY OF OPERATION

A Keras / TF model is built on each HPCC node and training data is distributed among the nodes. Distributed Synchronous Batch Gradient Descent is performed across nodes, synchronizing weights

periodically based on the 'batchSize' parameter. Each function performs its work in a distributed manner, using the built-in parallelization of HPCC. Weights are synchronized across nodes after 'batchSize' records are processed on each node.

## PROGRAM FLOW

The flow of a program using this interface is as follows:

- `GetSession()` – Initialized Keras / TF and returns a session token. This must be called before any other operations.
- Define the model, either as a Sequential model or a Functional model:
  - `DefineModel(...)` – Construct a Keras Sequential model by providing a list of Python statements, one to construct each layer of the neural network as well as an optional compile definition statement.
  - `DefineFuncModel(...)` – Construct a Keras Functional Model. This allows construction of complex models that cannot be expressed as a sequential set of layers. These include models with multiple inputs or outputs, or models that use divergence or convergence among different layers.
- `CompileMod(...)` – (Optional) Pass the Keras model compilation statement and perform it on the model. This is only required if the compile definition was not provided in `DefineModel` (above).
- `Fit(...)` – Trains the model across the nodes of the cluster, based on provided training data.
- `EvaluateMod(...)` – (Optional) Evaluate the model against a set of data (typically your validation or test data) and return the loss and any other metrics that were defined by your `compileDef`.
- `Predict(...)` – (Optional) Use the model to predict the output based on a provided set of input (X) data.
- `GetWeights(...)` – (Optional) Return the trained weights of all layers of the model.

## USE OF TENSORS

GNNI uses Tensors (effectively N-dimensional array representations) to provide data and weights in and out of Keras / TF. See the included Tensor module for details. These Tensor datasets provide an efficient way to store, distribute, and process N-Dimensional data. The data is packed into 'slices', which can be either sparse or dense, for efficiency and scalability purposes.

Tensors can be used to convey record-oriented information such as training data as well as block oriented data like weights. Both can be N-dimensional. For record-oriented data, the first shape component is set to 0 (unspecified) indicating that it can hold an arbitrary set of records.

For models with multiple inputs or outputs, Tensor Lists are used (see `Tensor.ecl` for details), with one Tensor per input or output.

## USE OF NumericField

GNNI also provides a set of interfaces which take in and emit data as 2-dimensional NumericField datasets (see `ML_Core.Types.NumericField`). This is purely for convenience for applications that don't require the N-Dimensional capabilities of the Tensor format. Internally, these functions translate the NumericField format into Tensors, and convert the output from Tensors to NumericField. These functions have the same names as the tensor functions, but with NF appended to the name (e.g. `FitNF(...)`, `PredictNF(...)`). Weights are always returned as Tensors, so there is no NF version of `GetWeights(...)`.

**SEQUENCING OF OPERATIONS** The Keras / Tensorflow operations take place under the hood from an ECL perspective. Therefore normal ECL data dependencies are not sufficient to ensure proper sequencing. For this reason, GNNI uses a series of tokens passed from one call to the next to ensure the correct order of command execution. For example:

- `GetSession()` returns a session-token which must be passed to `DefineModel()`
- Subsequent calls return a model-token which must be passed to the following call. Each call creates a new model token which becomes the input to the next call in sequence.
- It is critical that this token passing is chained, or calls may occur out of order. For example, `Fit()` could be called before `DefineModel()`, which would not produce good results.

## MULTIPLE MODEL SUPPORT

GNNI supports multiple Keras models within the same work unit. Multiple models are created by using multiple calls to `DefineModel()` using the same `sessionId`. The returned `modelIds` are used in subsequent calls to discriminate between the models. See `Test/MultiModel.ecl` for an example.

## WORKING WITH GPU<sub>S</sub>

GNN can be used with hardware acceleration (i.e. GPU<sub>S</sub>) provided certain configuration rules are followed:

- All servers have the same configuration in terms of number of GPU<sub>S</sub> per server
- The number of Thor nodes = GPU<sub>S</sub> Per Server \* Number of Servers
- The number of GPU<sub>S</sub> per Server is passed to `GetSession()`

One GPU will be allocated to each Thor node.

## PERFORMANCE CONSIDERATIONS

Performance of GNN is a complex topic, and it is very difficult to make recommendations as to the optimal configuration for training a given problem. Below are some observations regarding performance that may be useful in understanding the tradeoffs.

- Many factors influence the training performance, and these are interrelated in complex ways:

- The complexity of the network design.
  - The amount of training data (number of records, and record size).
  - The complexity of the relationship(s) being modeled.
  - The Learning Rate specified in the Compile line for the selected optimizer.
  - The number of nodes in the HPCC cluster.
  - GNN training parameters (see Fit Below). Specifically: batchSize, learningRateReduction, batchSizeReduction, and localBatchSize.
  - The random starting point of the neural network weights.
- It is important to separate the speed of running Epochs from the final loss achieved. Using large batchSize (i.e. the number of records to process on each node before synchronizing weights), will process epochs faster, but with less loss reduction on each epoch.
  - Once the optimal training loss is determined (e.g. by running multiple epochs until consistent gain no longer occurs), it is recommended to use the "trainToLoss" parameter to abort training when a given loss level is reached.
  - Training parameters usually need to be adjusted when running on different sized clusters. The number of records processed on each batch is nNodes \* batchSize. For a larger cluster, it may be necessary to reduce the batchSize to avoid blurring of the training. An alternative is to use the batchSizeReduction parameter, which will cause the batchSize to automatically reduce as the training progresses. In some cases, reducing the learning rate or using the learningRateReduction parameter can also compensate for larger batch sizes.
  - If the network doesn't converge (e.g. loss goes to infinity, or loss is unstable across epochs), it generally means that the learning rate is set too high, or the batchSize is too large.

## Children

1. [GetSession](#) : Initialize Keras on all nodes and return a "session" token to be used on the next call to GNNI
2. [DefineModel](#) : Define a Keras / Tensorflow model using Keras syntax
3. [DefineFuncModel](#) : DefineFuncModel(...) – Construct a Keras Functional Model
4. [ToJSON](#) : Return a JSON representation of the Keras model
5. [FromJSON](#) : Create a Keras model from previously saved JSON
6. [CompileMod](#) : Compile a previously defined Keras model
7. [GetWeights](#) : Return the weights currently associated with the model
8. [SetWeights](#) : Set the weights of the model from a list of Tensors
9. [GetLoss](#) : Get the accumulated average loss for the latest epoch
10. [Fit](#) : Train the model using synchronous batch distributed gradient descent
11. [EvaluateMod](#) : Determine the loss and other metrics in order to evaluate the model

12. [Predict](#) : Predict the results using the trained model
  13. [Shutdown](#)
  14. [FitNF](#) : Fit a model with 2 dimensional input and output using NumericField matrices
  15. [EvaluateNF](#) : Evaluate a model with 2 dimensional input and output using NumericField matrices
  16. [PredictNF](#) : Predict the results for a model with 2 dimensional input and output using NumericField matrixes for input and output
- 

## **GETSESSION** **GetSession**

[GNNI](#) \

<b>UNSIGNED4</b>	<b>GetSession</b>
(UNSIGNED GPUsPerServer = 0)	

Initialize Keras on all nodes and return a "session" token to be used on the next call to GNNI.

This function must be called before any other use of GNNI.

**PARAMETER** **GPUsPerServer** ||| UNSIGNED8 — – The number of GPUs per Server. This is only used when working with GPUs. See "WORKING WITH GPUs section of module documentation. Defaults to 0 when GPUs not used.

**RETURN** **UNSIGNED4** — A session token (UNSIGNED4) to identify this session.

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## **DEFINEMODEL** **DefineModel**

[GNNI](#) \

<b>UNSIGNED4</b>	<b>DefineModel</b>
(UNSIGNED4 sess, SET OF STRING ldef, STRING cdef = ")	

Define a Keras / Tensorflow model using Keras syntax. Optionally also provide a "compile" line with the compilation parameters for the model.

If no compile line is provided (`cdef`), then the compile specification can be provided in a subsequent call to `CompileMod` (below).

The symbols `"tf"` (for tensorflow) and `"layers"` (for `tf.keras.layers`) are available for use within the definition strings. See `GNN/Test/ClassicTest.ecl` for an annotated example.

**PARAMETER** `sess` ||| UNSIGNED4 — The session token from a previous call to `GetSession()`.

**PARAMETER** `ldef` ||| SET ( STRING ) — A set of python strings as would be passed to `Keras model.add()`. Each string defines one layer of the model.

**PARAMETER** `cdef` ||| STRING — (optional) A python string as would be passed to `Keras model.compile(...)`. This line should begin with `"compile"`. Model is implicit here.

**RETURN** UNSIGNED4 — A model token to be used in subsequent GNNI calls.

---

## DEFINEFUNCMODEL DefineFuncModel

GNNI \

UNSIGNED4	DefineFuncModel
(UNSIGNED sess, DATASET(FuncLayerDef) lDefs, SET OF STRING inputs, SET OF STRING outputs, STRING cdef = ")	

`DefineFuncModel(...)` – Construct a Keras Functional Model. This allows construction of complex models that cannot be expressed as a sequential set of layers. These include models with multiple inputs or outputs, or models that use divergence or convergence among different layers.

Layers are connected together using the `layerName` and `predecessor` fields of the `FuncLayerDef`. The inputs of a layer are connected to the predecessor layers in the order specified by the set of names in the `predecessor` field.

The inputs and outputs parameter specifies the names of the layers that form the input and output of the model.

This is similar to the Keras Functional API, except that the entire model is defined in one call rather than assembled piecemeal as in the Functional API. The same rules apply here as for the Keras Functional API, and there should be a simple translation of any program using the Functional API.

For models with multiple inputs, input is specified as a list of tensors (see `Tensor.ecl`).

For models with multiple outputs, output will be a list of tensors.

**PARAMETER** sess ||| UNSIGNED8 — The session token from a previous call to GetSession().

**PARAMETER** IDefs ||| TABLE ( FuncLayerDef ) — A series of layer definitions using the Types.FuncLayerDef format.

**PARAMETER** inputs ||| SET ( STRING ) — A list of the names of the layers that represent the inputs to the model.

**PARAMETER** outputs ||| SET ( STRING ) — A list of the names of the layers that represent the outputs of the model.

**PARAMETER** cdef ||| STRING — (optional) A python string as would be passed to Keras model.compile(...). This line should begin with "compile". Model is implicit here.

**RETURN** UNSIGNED4 —

**SEE** Types.FuncLayerDef

**SEE** Test.FuncModelTest.ecl

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## TOJSON ToJSON

GNNI \

<b>STRING</b>	<b>ToJSON</b>
(UNSIGNED4 mod)	

Return a JSON representation of the Keras model.

**PARAMETER** mod ||| UNSIGNED4 — The model token as previously returned from DefineModel(...) above.

**RETURN** **STRING** — A JSON string representing the model definition.

---



## FROMJSON FromJSON

GNNI \

UNSIGNED4	FromJSON
(UNSIGNED4 sess, STRING json)	

Create a Keras model from previously saved JSON.

Note that this call defines the model, but does not restore the compile definition or the trained model weights. CompileMod(...) should be called after this to define the model compilation parameters.

**PARAMETER** sess ||| UNSIGNED4 — A session token previously returned from GetSession(..).

**PARAMETER** json ||| STRING — A JSON string defining the model as previously returned from ToJSON(...).

**RETURN** UNSIGNED4 — A model token to be used in subsequent GNNI calls.

---

## COMPILEMOD CompileMod

GNNI \

UNSIGNED4	CompileMod
(UNSIGNED model, STRING compileStr)	

Compile a previously defined Keras model.

This is an optional call that can be used if you omit the compileDef parameter during DefineModel(...) or if the model was created via FromJSON(...).

The compile string uses the same python syntax as using Keras' model.compile(...). Model is implied in this call, so the line should begin with "compile".

The symbol "tf" (for tensorflow) is available for use within the compile string.

Example:

- '''compile(loss='categorical\_crossentropy', optimizer='adam', metrics=['accuracy'])'''

It is convenient to use the triple single quote('') syntax as it allows strings to cross line boundaries, and allows special characters such as single or double quotes without escaping.

There is no need to make this call if the compileDef was provided in the DefineModel(...) call.

The returned model token should be used in subsequent calls to GNNI.

**PARAMETER** model ||| UNSIGNED8 — A model token as returned from DefineModel(...) or FromJSON(...).

**PARAMETER** compileStr ||| STRING — A python formatted string defining the Keras "compile" call and its parameters.

**RETURN** UNSIGNED4 — A new model token that should be used in subsequent GNNI calls.

---

## GETWEIGHTS GetWeights

GNNI \

<b>DATASET</b> ( <u>t_Tensor</u> )	<b>GetWeights</b>
( <u>UNSIGNED4 model</u> )	

Return the weights currently associated with the model.

The weights are returned as a Tensor List containing the weights for each Keras layer as a separate Tensor.

The weights from a given layer can be extracted by simply filtering on the work-item (wi). The first layer will use wi = 1, and the Nth layer uses wi = N.

This call is typically made after training the model via Fit(...), but can also be called before Fit(...) to retrieve the initial weights.

**PARAMETER** model ||| UNSIGNED4 — The model token as returned from DefineModel(...), CompileMod(...), or Fit(...).

**RETURN** TABLE ( t\_Tensor ) — A t\_Tensor dataset representing the weights as a list of Tensors.

**SEE** Tensor.t\_Tensor

## SETWEIGHTS SetWeights

GNNI \

UNSIGNED4	SetWeights
(UNSIGNED4 model, DATASET(t_Tensor) weights)	

Set the weights of the model from a list of Tensors.

Typically, the weights to be set were originally obtained using `GetWeights(...)` above. They must be of the same number and shape as would be returned from `GetWeights(...)`.

These will contain one Tensor for each defined Keras layer. The shape of each tensor is determined by the definition of the layer.

**PARAMETER** model ||| UNSIGNED4 — The model token from the previous step.

**PARAMETER** weights ||| TABLE ( t\_Tensor ) — The Tensor List (DATASET(t\_Tensor)) containing the desired weights.

**RETURN** UNSIGNED4 — A new model token to be used in subsequent calls.

**SEE** Tenosr.t\_Tensor

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## GETLOSS GetLoss

GNNI \

REAL	GetLoss
(UNSIGNED4 model)	

Get the accumulated average loss for the latest epoch.

This represents the average per sample loss.

**PARAMETER** model ||| UNSIGNED4 — The model token as returned from `Fit(...)`.

**RETURN** REAL8 — The average loss.

---

UNSIGNED4	Fit
	<pre>(UNSIGNED4 model, DATASET(t_Tensor) x, DATASET(t_Tensor) y, UNSIGNED4 batchSize = 512, UNSIGNED4 numEpochs = 1, REAL trainToLoss = 0, REAL learningRateReduction = 1.0, REAL batchSizeReduction = 1.0, UNSIGNED4 localBatchSize = 32)</pre>

Train the model using synchronous batch distributed gradient descent.

The X tensor represents the independent training data and the Y tensor represents the dependent training data.

Both X and Y tensors should be record-oriented tensors, indicated by a first shape component of zero. These must also be distributed (not replicated) tensors. If the model specifies multiple inputs or outputs, then tensor lists should be supplied, using the work-item id (wi) to distinguish the order of the tensors in the tensor list (see Tensor.ecl).

BatchSize defines how many observations are processed on each node before weights are re-synchronized. There is an interaction between the number of nodes in the cluster, the batchSize, and the complexity of the model. A larger batch size will process epochs faster, but the loss reduction may be less per epoch. As the number of nodes is increased, a smaller batchSize may be required. The default batchSize of 512 is a good starting point, but may require tuning to increase performance or improve convergence (i.e. loss reduction). Final loss should be used to assess the fit, rather than number of epochs trained. For example, for a given neural network, a loss of .02 may be the optimal tradeoff between underfit and overfit. In that case the network should be trained to that level, adjusting number of epochs and batchSize to reach that level. Alternatively, the trainToLoss parameter can be used to automatically stop when a given level of loss is achieved. See the top-level module documentation for more insight on Performance Considerations.

**PARAMETER** model ||| UNSIGNED4 — The model token from the previous GNNI call.

**PARAMETER** x ||| TABLE ( t\_Tensor ) — The independent training data tensor or tensor list.

**PARAMETER** y ||| TABLE ( t\_Tensor ) — The dependent training data tensor or tensor list.

**PARAMETER** batchSize ||| UNSIGNED4 — The number of records to process on each node before re-synchronizing weights across nodes.

**PARAMETER** numEpochs ||| UNSIGNED4 — The number of times to iterate over the full training set.

**PARAMETER** trainToLoss ||| REAL8 — Causes training to exit before numEpochs is complete if the trainToLoss is met. Defaults to 0, meaning that all epochs will be run. When using trainToLoss, numEpochs should be set to a high value so that it does not exit before the training goal is met. Note that not all network / training data configurations can be trained to a given loss. The nature of the data and the network configuration limits the minimum achievable loss.

**PARAMETER** learningRateReduction ||| REAL8 — Controls how much the learning rate is reduced as epochs progress. For some networks, training can be improved by gradually reducing the learning rate. The default value (1.0), maintains the original learning rate across all epochs. A value of .5 would cause the learning rate to be reduced to half the original rate by the final epoch.

**PARAMETER** batchSizeReduction ||| REAL8 — Controls how much the batchSize is reduced as epochs progress. For some networks, training can be improved by gradually reducing the batchSize. The default value (1.0), maintains the original batchSize across all epochs. A value of .25 would cause the learning rate to be reduced to one quarter the original rate by the final epoch.

**PARAMETER** localBatchSize ||| UNSIGNED4 — The batch size to use when calling Keras Fit() on each local machine. The default (32) is recommended for most uses.

**RETURN** UNSIGNED4 — A new model token for use with subsequent GNNI calls.

---

## EVALUATEMOD EvaluateMod

GNNI \

<code>DATASET(Types.metrics)</code>	<code>EvaluateMod</code>
<code>(UNSIGNED4 model, DATASET(t_Tensor) x, DATASET(t_Tensor) y)</code>	

Determine the loss and other metrics in order to evaluate the model.

Returns a set of metrics including loss and any other metrics that were defined in the compile definition for a set of provided test data.

Both X and Y tensors should be record-oriented tensors, indicated by a first shape component of zero. These must also be distributed (not replicated) tensors.

This is typically used after training the model, using a segregated set of test data, in order to determine the "out of sample" performance (i.e. performance on data outside of the training set).

**PARAMETER** model ||| UNSIGNED4 — The model token from the previous GNNI call (e.g. Fit).

**PARAMETER** x ||| TABLE ( t\_Tensor ) — The independent test data tensor or tensor list.

**PARAMETER** y ||| TABLE ( t\_Tensor ) — The dependent test data tensor or tensor list.

**RETURN** TABLE ( { UNSIGNED4 metricId , STRING metricName , REAL8 value } ) — A dataset of metrics indicating the performance of the model.

**SEE** `Types.metrics`

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## PREDICT Predict

GNNI \

<code>DATASET(t_Tensor)</code>	<b>Predict</b>
<code>(UNSIGNED4 model, DATASET(t_Tensor) x)</code>	

Predict the results using the trained model.

The X tensor represents the independent (input) data for the neural network and the output is returned as a tensor or tensor list (for multiple output networks). Input and output will be Tensor Lists if there is more than one input or output tensor for the NN.

The X tensor should be a record-oriented tensor, indicated by a first shape component of zero. It must also be distributed (not replicated) tensor.

**PARAMETER** model ||| UNSIGNED4 — A model token as returned from the previous GNNI call (e.g. Fit).

**PARAMETER** x ||| TABLE ( t\_Tensor ) — The independent (i.e. input) data tensor or tensor list.

**RETURN** TABLE ( t\_Tensor ) — The output predicted by the model as a record-oriented tensor or tensor list.

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## SHUTDOWN Shutdown

GNNI \

<code>UNSIGNED4</code>	<b>Shutdown</b>
<code>(UNSIGNED4 model)</code>	

**PARAMETER** model ||| UNSIGNED4 — A model token as returned from a previous GNNI call.

**RETURN** **UNSIGNED4** — A new model token.

**NODOC** Shutdown Keras / Tensorflow and free up any allocated memory. This function is not required at this time but is here for future use.

---

## **FITNF** FitNF

GNNI \

<b>UNSIGNED4</b>	<b>FitNF</b>
	<pre>(UNSIGNED4 model, DATASET(NumericField) x, DATASET(NumericField) y, UNSIGNED4 batchSize = 512, UNSIGNED4 numEpochs = 1, REAL trainToLoss = 0, REAL learningRateReduction = 1.0, REAL batchSizeReduction = 1.0, UNSIGNED4 localBatchSize = 32)</pre>

Fit a model with 2 dimensional input and output using NumericField matrices.

This is a NumericField wrapper around the Fit function. See Fit (above) for details.

**PARAMETER** **model** ||| **UNSIGNED4** — The model token from the previous GNNI call.

**PARAMETER** **x** ||| **TABLE ( NumericField )** — The independent training data.

**PARAMETER** **y** ||| **TABLE ( NumericField )** — The dependent training data.

**PARAMETER** **batchSize** ||| **UNSIGNED4** — The number of records to process on each node before re-synchronizing weights across nodes.

**PARAMETER** **numEpochs** ||| **UNSIGNED4** — The number of times to iterate over the full training set.

**PARAMETER** **trainToLoss** ||| **REAL8** — Causes training to exit before numEpochs is complete if the trainToLoss is met. Defaults to 0, meaning that all epochs will be run. When using trainToLoss, numEpochs should be set to a high value so that it does not exit before the training goal is met. Note that not all network / training data configurations can be trained to a given loss. The nature of the data and the network configuration limits the minimum achievable loss.

**PARAMETER** **learningRateReduction** ||| **REAL8** — Controls how much the learning rate is reduced as epochs progress. For some networks, training can be improved by gradually reducing the learning rate. The default value (1.0), maintains the original learning rate across all epochs. A value of .5 would cause the learning rate to be reduced to half the original rate by the final epoch.

**PARAMETER** batchSizeReduction ||| REAL8 — Controls how much the batchSize is reduced as epochs progress. For some networks, training can be improved by gradually reducing the batchSize. The default value (1.0), maintains the original batchSize across all epochs. A value of .25 would cause the learning rate to be reduced to one quarter the original rate by the final epoch.

**PARAMETER** localBatchSize ||| UNSIGNED4 — The batch size to use when calling Keras Fit() on each local machine. The default (32) is recommended for most uses.

**RETURN** UNSIGNED4 — A new model token for use with subsequent GNNI calls.

**SEE** ML\_Core.Types.NumericField

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## EVALUATENF EvaluateNF

GNNI \

<code>DATASET(Types.metrics)</code>	<code>EvaluateNF</code>
<code>(UNSIGNED4 model, DATASET(NumericField) x, DATASET(NumericField) y)</code>	

Evaluate a model with 2 dimensional input and output using NumericField matrices.

This is a NumericField wrapper around the EvaluateMod function. See EvaluateMod (above) for details.

**PARAMETER** model ||| UNSIGNED4 — The model token from the previous GNNI call.

**PARAMETER** x ||| TABLE ( NumericField ) — The independent test data.

**PARAMETER** y ||| TABLE ( NumericField ) — The dependent test data.

**RETURN** TABLE ( { UNSIGNED4 metricId , STRING metricName , REAL8 value } ) —  
A dataset of metrics indicating the performance of the model.

**SEE** Types.metrics

**SEE** ML\_Core.Types.NumericField

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## PREDICTNF PredictNF

GNNI \

<b>DATASET(NumericField)</b>	<b>PredictNF</b>
(UNSIGNED4 model, DATASET(NumericField) x)	

Predict the results for a model with 2 dimensional input and output using NumericField matrixes for input and output.

This a a NumericField wrapper around the Predict function. See Predict (above) for details.

**PARAMETER** model ||| UNSIGNED4 — A model token as returned from the previous GNNI call (e.g. Fit).

**PARAMETER** x ||| TABLE ( NumericField ) — The independent (i.e. input) data NumericField matrix.

**RETURN** TABLE ( { UNSIGNED2 wi , UNSIGNED8 id , UNSIGNED4 number , REAL8 value } ) — The output predicted by the model as a NumericField matrix.

**SEE** ML\_Core.Types.NumericField

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# Tensor

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## IMPORTS

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python3 | __versions.ML_Core.V3_2_2.ML_Core |  
__versions.ML_Core.V3_2_2.ML_Core.Types | std.system.Thorlib | std.system.Log |
```

## DESCRIPTIONS

### **TENSOR** Tensor

	Tensor
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ECL Tensor Module.

Overview:

Tensor datasets provide an efficient way to store, distribute, and process N-Dimensional data. Tensors represent an N dimensional array. They can represent data of from 0 dimensions (scalar), 1 dimension (vector), 2 dimensions (matrix), or up to a high number of dimensions.

Tensors are typed – the module currently only supports REAL4 type Tensors, but is set up to accomodate other data types in the future. The Tensor.R4 submodule is used to manage REAL4 type Tensors.

Two main record types are defined for use with Tensors:

- TensorData is used to define the content of a Tensor. This is a sparse data format – each record represents one cell of the Tensor.
- t\_Tensor is used to define the Tensor's metadata such as it's N dimensional shape, its type, etc. It manages the tensor as a series of slices (i.e. partitions) with the data packed into the slices in either sparse or dense form, depending on the nature of the data.

A Tensor is created by calling the `MakeTensor(...)` function with the appropriate meta-data and a `TensorData` dataset.

Inversely, the data is read out of a Tensor using the `GetData(...)` function.

Tensor Shape:

A Tensor is defined with a shape. Shapes are given by a set of integers defining the length of each dimension of the Tensor. For example: shape `[4, 3, 2]` represents a 4 x 3 x 2 tensor. Record-oriented Tensors may have the first shape component unspecified. Zero is used to indicate that the index is unspecified. For example: a shape of `[0, 5, 8, 4]` specifies a Tensor with an unspecified number of rows, each with a 3 dimensional shape `[5, 8, 4]`.

Distribution Modes:

Tensors have 2 distribution modes:

- Distributed – The slices are distributed across the nodes of the cluster.
- Replicated – All slices are present on all nodes (for local operations on each node).

Tensor Lists:

A `t_Tensor` dataset also allows for multiple tensors of different shapes to be stored in a single dataset. The work item (`wi`) field of the Tensor is used to distinguish between the different Tensors. A Tensor with multiple work items is considered an ordered list of Tensors.

Tensor Data Types:

At some point, we will support Tensors of different data types such as `REAL4`, `REAL8`, `INTEGER4`, `INTEGER8`, and `STRING`. This release, however, supports only `REAL4` type tensors. The methods operating on these tensors are found in the `R4` (i.e. `REAL4`) submodule. Future versions will add more submodules for different tensor types.

The `dat` module (e.g. `Tensor.R4.dat`) provides methods for packing and unpacking scalar, vector, and matrix data. These methods allow, for example, a Tensor of shape `[2,3,3]` to be built by packing two 3 x 3 matrices into a Tensor.

EXAMPLES:

```
// Scalar (0-D)
tensDatScalar := Tensor.R4.dat.fromScalar(3.14159); // 0D (Scalar) Tensor data
// Vector (1-D)
tensDatVector := Tensor.R4.dat.fromVector([.013, .015, -.312, 0, 1.0]); // 1D (Vector) Tensor
// Matrix (2-D)
tensDatMatrix := Tensor.R4.dat.fromMatrix(myNF); // 2D (Matrix) Tensor data
// N-D Tensor
```

```
tensDat := DATASET([\{[1,1,1,1], .01\},
                    \{[5,2,111,3], .02\}], Tensor.R4.TensDat); // 4D (nD) Tensor data
```

## Children

1. [R4](#) : REAL4 tensor type attributes

## **R4** R4

[Tensor](#) \

<b>R4</b>
-----------

REAL4 tensor type attributes

## Children

1. [TensData](#) : REAL4 Tensor Data Format
2. [t\\_SparseDat](#) : Record format for the sparseData child dataset within a Tensor
3. [t\\_Tensor](#) : Record format for a REAL4 valued Tensor slice
4. [dat](#) : Submodule for manipulating TensorData
5. [Replicate](#) : Replicate the Tensor Slices to all nodes of the cluster
6. [MakeTensor](#) : Make a Tensor from a set of TensorData and some meta-data
7. [GetData](#) : Extract the data from a tensor and return it in sparse TensData format
8. [Reshape](#) : Reshape a tensor to a new compatible shape
9. [Add](#) : Add two tensors
10. [GetRecordCount](#) : Get the number of records in a record-oriented Tensor
11. [AlignTensors](#) : Aligns a list of Tensors (seperated by wi) so that all of the tensors' corresponding records are stored on the same node

## TENSDATA TensData

Tensor \ R4 \

	TensData
--	----------

REAL4 Tensor Data Format.

Note: This is sparse format, and any cells not supplied are assumed to be zero.

**FIELD** indexes ||| SET ( UNSIGNED4 ) — – the N-dimensional index of this tensor cell

**FIELD** value ||| REAL4 — – the numeric value of this tensor cell.

---

## T\_SPARSEDAT t\_SparseDat

Tensor \ R4 \

	t_SparseDat
--	-------------

Record format for the sparseData child dataset within a Tensor

**FIELD** offset ||| UNSIGNED4 — The offset within the tensor slice.

**FIELD** value ||| REAL4 — The value at the given offset within the tensor slice.

---

## T\_TENSOR t\_Tensor

Tensor \ R4 \

	t_Tensor
--	----------

Record format for a REAL4 valued Tensor slice.

Tensors are stored as a Dataset of Tensor slices. Each slice contains Tensor metadata (e.g. shape, dataType), as well as the tensor data elements within the slice. Slices can be densely packed or sparsely packed depending on the density of the source data.

- FIELD** nodeId ||| UNSIGNED4 — The node number on which this slice currently resides.
- FIELD** wi ||| UNSIGNED4 — The work-item allows a list of tensors to be stored within a single dataset. Wi of 1 indicates the first tensor in the list, 2 for the second, etc.
- FIELD** sliceId ||| UNSIGNED4 — The id of this tensor slice. Each tensor is represented as 1 or more slices. Each tensor in a tensor list can have the same sliceIds.
- FIELD** shape ||| SET ( UNSIGNED4 ) — The shape of the tensor (e.g. [10, 20, 5]).
- FIELD** dataType ||| UNSIGNED4 — The data type for each cell of the tensor.
- FIELD** maxSliceSize ||| UNSIGNED4 — The size of a full slice for this tensor.
- FIELD** sliceSie ||| — The size of this slice. Slices 1 - (N-1) will full slices, while slice N may have less than the maxSliceSize data.
- FIELD** denseDat ||| — A packed block of REAL4 values representing the linearized data within this slice.
- FIELD** sparseDat ||| — A child dataset for storing sparse data as a set of local offset and value pairs.  
Note: Only denseData or sparseData are used for any slice. The other will be empty.
- FIELD** sliceSize ||| UNSIGNED4 — No Doc
- FIELD** densedata ||| SET ( REAL4 ) — No Doc
- FIELD** sparsedata ||| TABLE ( t\_SparseDat ) — No Doc

## DAT dat

Tensor \ R4 \

dat
-----

Submodule for manipulating TensorData.

### Children

1. [fromScalar](#) : Create tensor data from a scalar
2. [fromVector](#) : Create tensor data from a vector

3. `fromMatrix` : Create tensor data from a NumericField matrix
4. `toScalar` : Extract a scalar from a position within the Tensor data
5. `toVector` : Extract a vector of values from a TensData dataset
6. `toMatrix` : Extract a matrix of values from a TensData dataset

---

## FROMSCALAR `fromScalar`

Tensor \ R4 \ dat \

<b>DATASET(TensData)</b>	<b>fromScalar</b>
(REAL4 value, t_Indexes atIndx = [])	

Create tensor data from a scalar.

The scalar will be placed at the "atIndex" in the tensor.

Example: `tdata := t_Tensor.R4.dat.fromScalar('3.14159', [1,3,1]);` // The cell will be placed at index [1, 3, 1]

**PARAMETER** value ||| REAL4 — The value of the tensor cell at atIndex.

**PARAMETER** atindx ||| SET ( UNSIGNED4 ) — No Doc

**RETURN** TABLE ( TensData ) — A TensData dataset with one record.

**PARM** atIndx The index of the cell being defined.

---

## FROMVECTOR `fromVector`

Tensor \ R4 \ dat \

<b>DATASET(TensData)</b>	<b>fromVector</b>
(SET OF REAL4 vec, t_Indexes atIndx = [])	

Create tensor data from a vector.

The elements of the array will be placed under "atIndx". The first element will be at [atIndx, 1], and the Nth will be at [atIndx, N].

Example: `tdata := t_Tensor.R4.dat.fromVector([.1, .2, -.1, -.2], [1, 3]);` // The first element (.1) will be at index [1, 3, 1].

**PARAMETER** vec ||| SET ( REAL4 ) — A set of numbers representing the value of the vector.

**PARAMETER** atIndx ||| SET ( UNSIGNED4 ) — The index under which to place the vector.

**RETURN** TABLE ( TensData ) — A TensData dataset with length the same as the vector.

---

## FROMMATRIX fromMatrix

Tensor \ R4 \ dat \

<b>DATASET(TensData)</b>	<b>fromMatrix</b>
(DATASET(NumericField) mat, t_Indexes atIndx = [])	

Create tensor data from a NumericField matrix.

The elements of the matrix will be placed at: [atIndx, id, number], where id and number are the row and column indexes for each matrix cell.

Note: The work-item (wi) field of the NF matrix is ignored, so multiple work-items should not be used in the input matrix.

Example: `tdata := t_Tensor.R4.dat.fromMatrix(myNumericFieldDS, [3,5,2]);` // The first element of the matrix will be at: [3,5,2,1,1].

**PARAMETER** mat ||| TABLE ( NumericField ) — A ML\_Core.NumericField dataset representing the matrix to be added.

**PARAMETER** atIndx ||| SET ( UNSIGNED4 ) — The index under which to place this matrix in the tensor data.

**RETURN** TABLE ( { SET ( UNSIGNED4 ) indexes , REAL4 value } ) — A TensorData dataset with length the same as the NumericField data passed in.



**SEE** ML\_Core.Types.NumericField

---

## TOSCALAR toScalar

Tensor \ R4 \ dat \

REAL4	toScalar
(DATASET(TensData) tens, t_Indexes fromIndx = [])	

Extract a scalar from a position within the Tensor data.

Note: If the tensor shape has 5 indexes, then fromIndex should be 5 long, as the scalar is extracted from the actual tensor cell.

Example: REAL4 val := toScalar(myt\_TensorDat, [1,3]); // Extract a cell from position [1,3] of a 2-D tensor.

**PARAMETER** tens ||| TABLE ( TensData ) — A TensData dataset from which to extract.

**PARAMETER** fromIndx ||| SET ( UNSIGNED4 ) — The index from which to extract the cell value.

**RETURN** REAL4 — The extracted value as a REAL4.

---

## TOVECTOR toVector

Tensor \ R4 \ dat \

DATASET(NumericField)	toVector
(DATASET(TensData) tens, t_Indexes fromIndx = [])	

Extract a vector of values from a TensData dataset.

If the tensor shape has N terms, then the fromIndx should contain N-1 terms. It will return the cells: [fromIndx, 1] through [fromIndx, M], where M is the last shape term.

The data is returned as a NumericField matrix with a single row (i.e. `id = 1`). This is used rather than a SET to allow for sparse data. Only non-zero cells are returned. The number field indicates the position within the vector.

Example: `DATASET(NumericField) vec := toVector(myt_TensorDat, [5,2]);` // Extract a vector from [5,2] in the 3-D tensor data.

**PARAMETER** tens ||| TABLE ( TensData ) — The TensorData dataset from which to extract the vector.

**PARAMETER** fromIndex ||| — the index from which to extract.

**PARAMETER** fromindx ||| SET ( UNSIGNED4 ) — No Doc

**RETURN** TABLE ( { UNSIGNED2 wi , UNSIGNED8 id , UNSIGNED4 number , REAL8 value } ) — A vector as a single row of a NumericField matrix.

**SEE** ML\_Core.Types.NumericField

## TOMATRIX toMatrix

Tensor \ R4 \ dat \

<code>DATASET(NumericField)</code>	<code>toMatrix</code>
<code>(DATASET(TensData) tens, t_Indexes fromIndx = [])</code>	

Extract a matrix of values from a TensData dataset.

If the tensor shape has N terms, then the fromIndx should contain N-2 terms. It will return the cells: [fromIndx, 1, 1] through [fromIndx, K, M], where K is the second to last shape term and M is the last shape term.

Example: `myNF := toNumericField(myt_TensorDat, [3,11]);` // Extract a matrix from a 4-D tensor data dataset.

**PARAMETER** tens ||| TABLE ( TensData ) — The TensorData dataset from which to extract.

**PARAMETER** fromIndex ||| SET ( UNSIGNED4 ) — The index from which to extract the matrix.

**RETURN** TABLE ( { UNSIGNED2 wi , UNSIGNED8 id , UNSIGNED4 number , REAL8 value } ) — A matrix in NumericField format.

**SEE** ML\_Core.Types.NumericField

---

## REPLICATE Replicate

Tensor \ R4 \

<code>DATASET(t_Tensor)</code>	<b>Replicate</b>
<code>(DATASET(t_Tensor) tens)</code>	

Replicate the Tensor Slices to all nodes of the cluster.

This is used to provide a copy of the Tensor on each node of the cluster.

**PARAMETER** tens ||| TABLE ( t\_Tensor ) — A t\_Tensor dataset to be replicated.

**RETURN** TABLE ( { UNSIGNED4 nodeId , UNSIGNED4 wi , UNSIGNED4 sliceId , SET ( UNSIGNED4 ) shape , UNSIGNED4 dataType , UNSIGNED4 maxSliceSize , UNSIGNED4 sliceSize , SET ( REAL4 ) denseData , TABLE ( t\_SparseDat ) sparseData } ) — A replicated t\_Tensor dataset. If the original dataset contained N slices, the new dataset will contain N x nNodes slices.

---

## MAKETENSOR MakeTensor

Tensor \ R4 \

<code>DATASET(t_Tensor)</code>	<b>MakeTensor</b>
<code>(t_Indexes shape, DATASET(TensData) contents = DATASET([], TensData), BOOLEAN replicated = FALSE, UNSIGNED4 wi = 1, UNSIGNED4 forceMaxSliceSize = 0)</code>	

Make a Tensor from a set of TensorData and some meta-data.

Tensors may be replicated (e.g. copied locally to each node), or distributed (slices spread across nodes).

**PARAMETER** shape ||| SET ( UNSIGNED4 ) — The desired shape of the Tensor (e.g. [10, 5, 2]).

**PARAMETER** contents ||| TABLE ( TensData ) — Dataset of TensData representing the contents of the Tensor. If omitted, the tensor will be empty (i.e. all zeros).

**PARAMETER** replicated ||| BOOLEAN — True if this tensor is to be replicated to all nodes. Default = False (i.e. distributed).

**PARAMETER** wi ||| UNSIGNED4 — Work-item. This field allows multiple Tensors to be stored in the same dataset. Default = 1. This field should always be 1 for a single Tensor dataset. For a Tensor list, wi should always go from 1 to nTensors.

**PARAMETER** forceMaxSliceSize ||| UNSIGNED4 — If non-zero, it will override the default sizing of slices. Needed internally, but should always use the default (0) for external uses.

**RETURN** TABLE ( { UNSIGNED4 nodeId , UNSIGNED4 wi , UNSIGNED4 sliceId , SET ( UNSIGNED4 ) shape , UNSIGNED4 dataType , UNSIGNED4 maxSliceSize , UNSIGNED4 sliceSize , SET ( REAL4 ) denseData , TABLE ( t\_SparseDat ) sparseData } ) — A dataset of t\_Tensor representing the Tensor object.

---

## GETDATA GetData

Tensor \ R4 \

<b>DATASET(TensData)</b>	<b>GetData</b>
(DATASET(t_Tensor) tens)	

Extract the data from a tensor and return it in sparse TensData format.

This is essentially the inverse of the MakeTensor(...) method.

**PARAMETER** tens ||| TABLE ( t\_Tensor ) — The t\_Tensor dataset from which to extract the data

**RETURN** TABLE ( TensData ) — TensData dataset of non-zero tensor data (sparse form).

---

## RESHAPE Reshape

Tensor \ R4 \

<b>Reshape</b>
(DATASET( <u>t_Tensor</u> ) <u>tens</u> , <u>t_Indexes</u> <u>newShape</u> )

Reshape a tensor to a new compatible shape.

Returns a new tensor with the desired shape.

If the shapes were not compatible, an empty tensor is returned.

**PARAMETER** tens ||| TABLE ( t\_Tensor ) — The tensor to be reshaped.

**PARAMETER** newShape ||| SET ( UNSIGNED4 ) — The desired new shape.

**RETURN** TABLE ( { UNSIGNED4 nodeId , UNSIGNED4 wi , UNSIGNED4 sliceId , SET ( UNSIGNED4 ) shape , UNSIGNED4 dataType , UNSIGNED4 maxSliceSize , UNSIGNED4 sliceSize , SET ( REAL4 ) denseData , TABLE ( t\_SparseDat ) sparseData } ) — A new tensor with the desired shape, if the shapes were compatible. Otherwise, an empty tensor.

## ADD Add

Tensor \ R4 \

DATASET( <u>t_Tensor</u> )	<b>Add</b>
(DATASET( <u>t_Tensor</u> ) <u>t1</u> , DATASET( <u>t_Tensor</u> ) <u>t2</u> )	

Add two tensors.

This performs cell-wise addition of the contents of the two input tensors and returns a new tensor representing the sum of the two tensors.

Both tensors must be of the same shape.

This function can also add two tensor lists. Each tensor of list 1 must be of the same shape as the corresponding tensor in list 2. The lists must also be of the same length.

**PARAMETER** t1 ||| TABLE ( t\_Tensor ) — The first tensor or tensor list.

**PARAMETER** t2 ||| TABLE ( t\_Tensor ) — The second tensor or tensor list.

**RETURN** TABLE ( { UNSIGNED4 nodeId , UNSIGNED4 wi , UNSIGNED4 sliceId , SET ( UNSIGNED4 ) shape , UNSIGNED4 dataType , UNSIGNED4 maxSliceSize , UNSIGNED4 sliceSize , SET ( REAL4 ) denseData , TABLE ( t\_SparseDat ) sparseData } ) — A new Tensor (DATASET(t\_Tensor)) representing t1 + t2.

## GETRECORDCOUNT GetRecordCount

Tensor \ R4 \

UNSIGNED	GetRecordCount
(DATASET(t_Tensor) tens)	

Get the number of records in a record-oriented Tensor.

**PARAMETER** tens ||| TABLE ( t\_Tensor ) — The input Tensor.

**RETURN** UNSIGNED8 — The number of records in the distributed tensor.

## ALIGNTENSORS AlignTensors

Tensor \ R4 \

DATASET(t_Tensor)	AlignTensors
(DATASET(t_Tensor) tensList)	

Aligns a list of Tensors (seperated by wi) so that all of the tensors' corresponding records are stored on the same node. This prevents different sized records from being distributed differently among the nodes.

In most cases, the inputs and outputs to a neural network during training, and the inputs during prediction should be aligned so that various aspects of the same observation are presented together.

**PARAMETER** tens ||| — A Tensor List with at least two tensors identified by sequential work item ids from 1-N.

**PARAMETER** tenslist ||| TABLE ( t\_Tensor ) — No Doc

**RETURN TABLE ( t\_Tensor )** — A new Tensor List with the same number of tensors as the input list, with all of the tensors being aligned.

---

# Types

---

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## DESCRIPTIONS

### **TYPES** Types

	Types
--	-------

Type definitions for use with the GNNI Interface.

#### Children

1. [metrics](#) : Return structure for call to EvaluateMod
2. [FuncLayerDef](#) : Record to use for defining complex (i.e

---

### **METRICS** metrics

[Types](#) \

	metrics
--	---------

Return structure for call to EvaluateMod.

Contains a series of metrics and their values.

**FIELD** metricId ||| UNSIGNED4 — A sequential id to maintain the metrics' order.

**FIELD** metricName ||| STRING — The Keras name identifying the metric.

**FIELD** value ||| REAL8 — The value of the metric.



---

## **FUNCLAYERDEF** FuncLayerDef

Types \

<b>FuncLayerDef</b>
---------------------

Record to use for defining complex (i.e. Non-Sequential, Functional) models using the DefineFuncModel() GNNI method.

**FIELD** layername ||| STRING — No Doc

**FIELD** layerdef ||| STRING — No Doc

**FIELD** predecessors ||| SET ( STRING ) — No Doc

---

# Utils

---

[Go Up](#)

## IMPORTS

GNN.Tensor |

## DESCRIPTIONS

### **UTILS** Utils

	Utils
--	-------

Utility module for GNN. Contains various utility functions for use with GNN.

#### Children

1. [ToOneHot](#) : Convert Tensor Data to OneHot Encoding
2. [FromOneHot](#) : Convert One Hot encoded 2-D tensor data to class label format
3. [Probabilities2Class](#) : Convert a set of class probabilities to a class label  
Class probabilities are typically returned from a "softmax" activation function

---

### **TOONEHOT** ToOneHot

[Utils](#) \

<b><code>DATASET(TensDat)</code></b>	<b>ToOneHot</b>
<code>(DATASET(TensDat) classDat, UNSIGNED numClasses)</code>	

Convert Tensor Data to OneHot Encoding.

Input is a 1-D tensor data set with the value of each observation being the class.

Returns a 2-D TensDat dataset with numClasses being the cardinality of the 2nd dimension. The value will be 1 for the cell with second dimension corresponding to the class. All others will be zero. Since TensDat is a sparse format, all zero cells will be skipped.

Note that Classes are 0-based. Class 0 will be at final index = 1. Class 5 will be at final index = 6.

**PARAMETER** classDat ||| TABLE ( TensDat ) — A 1-D tensor with the index being the observation number, and the value ((0-(numClasses-1)) corresponds to the class label.

**PARAMETER** numClasses ||| UNSIGNED8 — The number of possible values for the class variable.

**RETURN** TABLE ( { SET ( UNSIGNED4 ) indexes , REAL4 value } ) — A 2-D set of TensData one hot encoded.

**SEE** Tensor.R4.TensData

## FROMONEHOT FromOneHot

[Utils \](#)

<b><code>DATASET(TensDat)</code></b>	<b>FromOneHot</b>
<code>(DATASET(TensDat) ohTens)</code>	

Convert One Hot encoded 2-D tensor data to class label format.

Input is a 2-D One Hot encoded TensDat dataset, as produced by ToOneHot above.

Output is a 1-D set of class labels corresponding to the highest value of the One Hot encoded fields for each observation.

Note that returned classes are zero based.

**PARAMETER** ohTens ||| TABLE ( TensDat ) — A one hot encoded 2-D tensor data set.

**RETURN** TABLE ( { SET ( UNSIGNED4 ) indexes , REAL4 value } ) — A 1-D dataset of TensData with the value of each observation being the class label.

**SEE** Tensor.R4.TensData

---

## PROBABILITIES2CLASS Probabilities2Class

Utils \

<b>DATASET</b> (TensDat)	Probabilities2Class
(DATASET(TensDat) td)	

Convert a set of class probabilities to a class label

Class probabilities are typically returned from a "softmax" activation function. This returns the class label associated with the maximum probability label.

Note that this function simply calls FromOneHot, which implements this functionality. Both names are included because it is sometimes more intuitive to think of the operation in different ways.

**PARAMETER** td ||| TABLE ( TensDat ) — A 2-D tensor data set with a probability for each class.

**RETURN** TABLE ( { SET ( UNSIGNED4 ) indexes , REAL4 value } ) — A 1-D dataset of TensData with a class label for each observation.

**SEE** FromOneHot

**SEE** Tensor.R4.TensData

---