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# **GPTwoSample Documentation**

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**Max Zwiebele, Oliver Stegle**

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`gptwosample.py` is a tool to run two-sample tests on time series differential gene expression experiments. It can either be called from the command line or using the interactive Python Modules. Here, we will explore usage from the command line, for detailed description, refers to the other sections.



# COMMAND LINE TOOL

`gptwosample` is designed to compare two gene expression time series experiments, including the possibility for several replicates in each experiment. The test fits latent functions to both time series, comparing the assumption that all data originated from a single latent process (*common model fit*) or a two distinct separate time series (*individual model fit*). See [Stegle2010] for details. The Raw gene expression data can be supplied via simple CSV files, one for each experiments. The data format is flexible, permits missing values and non-synchronized time points. Fur full details please see *Data format*.

## 1.1 Installing the package

To install `gptwosample` run:

```
pip install gptwosample
```

or run:

```
python setup.py install
```

from `gptwosample` directory if you downloaded the source.

This will install a script `gptwosample` into you python bin. In some cases this bin is not in `$PATH` and must be included extra.

Try printing the full help of the script using:

```
gptwosample --help
```

restart your unix shell if it is not yet registered.

To run optional package tests before installing run:

```
python setup test
```

## 1.2 Example usage

Once the data has been prepared, `GPTwoSample` can be executed from the unix command line.

General command line parameters of interest include:

```
--help  
-v
```

Also, to create plots of the fitted functions, which creates verbose plots illustrating the fit for every tested gene:

-p

For example, to run the basic `gptwosample` model on the tutorial datasets provided alongside the package including verbose output and plots, run:

```
gptwosample -v -p -t -o ./examplerun/ examples/ToyCondition1.csv examples/ToyCondition2.csv
```

This stores results in `./examplerun/`. Quantitative readouts summarizing the differential expression stores are provided in “results.csv” (see *Result structure* for format). Plots in will be saved in a subfolder `./examplerun/plots/`.

## 1.3 Further Details

### 1.3.1 Parameter options

Calling signature:

```
gptwosample [-h] [-o DIR] [-t] [-c N] [-p] [-v] [--version] [--backend [PDF,...]] FILE FILE
```

where:

```
FILE          treatment/control files to compare against each other
-h, --help    show this help message and exit
-o DIR, --out DIR set output dir [default: ./twosample_out/]
-t, --timeshift account for timeshifts in data [default: False]
-c N, --confounder N account for N confounders in data [default: 0]
-p, --plot    plot data into outdir/plots? [default: False]
-v, --verbose set verbosity level [default: 0]
--version     show program's version number and exit
--backend [PDF,...] matplotlib backend - see matplotlib.use(backend)
```

### 1.3.2 Data format

The format of the two `.csv` files (`FILE FILE` in usage) is as follows:

<i>arbitrary</i>	<b>x1</b>	<b>...</b>	<b>x1</b>
Gene ID 1	y1 replicate 1	...	y1 replicate 1
...	...	...	...
Gene ID 1	y1 replicate k1	...	y1 replicate k1
...			
Gene ID n	y1 replicate 1	...	y1 replicate 1
...	...	...	...
Gene ID n	y1 replicate kn	...	y1 replicate kn

See `gptwosample/examples/ToyCondition{1,2}.csv` for example data files. All values, which cannot be translated by `float()` will be treated as missing values in the model.

### 1.3.3 Accounting for confounding factors

We detect common confounding factors using probabilistic principal component analysis modeled by gaussian process latent variable models (GPLVM) [Lawrence2004]. This probabilistic approach to detect low dimensional significant features can be interpreted as detecting common confounding factors in time series experiments by applying GPLVM

in advance to two-sample tests of [Stegle2010] on the whole dataset. Two-sample tests on Gaussian Processes decide differential expression based on the bayes factor of marginal probabilities for control and treatment being modeled by one common or two separate underlying function(s). As GPLVM is based on Gaussian Processes it provides a covariance structure of confounders in the dataset. We take this covariance structure between features to build up a two-sample Gaussian Process model taking confounding factors throughout the dataset into account.

To account for confounding factors in `gptwosample` simply at the option `-c N` to the run call, where `N` is the number of confounding factors to learn.

### 1.3.4 Timeshift detection between replicates

A novel covariance function detecting timeshifts between time series accounts for temporal mismatches between time series, (of replicates and samples) which share similar patterns, shifted in time. This allows for additional correction of confounding variation in time, as treatment might slow down reaction time of cell-cycle genes, leading to a bunch of falsely positive predicted non differential expressed genes downstream.

To enable timeshift detection add the flag `-t` to the run script. Timeshifts for all replicates will be reported in `results.csv`, where the order of replicates is the same order as in the input files `FILE FILE` (see *Parameter options*).

### 1.3.5 Result structure

The results are given in form of a `results.csv`. Each line corresponds to the results for one gene. The results file is structured as follows:

```
| Gene ID | Bayes Factor | [Learnt covariance function parameters] |
```

The `Gene ID` is the ID given in the input files. The `Bayes Factor` is a log-score for model comparison of the individual model against the common model. The individual model assumes both samples (treatment and control) to be modelled individually by one Gaussian process each. In contrast the common model assumes both samples to be modelled by one Gaussian Process. Both likelihoods are computed and the score is created by contrasting the both likelihoods:

$$\mathcal{BF} = \ln \frac{p(\text{Individual model})}{p(\text{Common model})}$$

All plots are saved in a subfolder `<outdir>/plots/`

### 1.3.6 Step by step tutorial & examples

Once the data has been prepared, `gptwosample` can be executed from the unix command line. See the full usage information in *Parameter options*.

See format for input data `.csv` files in *Data format*.

Make sure you either install `gptwosample` (*Installing the package*) .. or `cd`

into the extracted `gptwosample` folder before running this tutorial.

Try printing the full help of the script using:

```
python gptwosample --help
```

If an error occurs, you probably `cd` one level too deep and you can `cd ..` up one level.

In this tutorial we will build up a full usage call of `gptwosample`. First, we want to run `gptwosample` verbosly, thus the call so far looks like:

```
gptwosample -v
```

To enable plotting we provide the switch `-p` to the script:

```
gptwosample -v -p
```

We want to correct for timeshifts (more on *Timeshift detection between replicates*), thus we enable the timeshift switch `-t`:

```
gptwosample -v -p -t
```

Next we could additionally learn  $x$  confounding factors (see *Accounting for confounding factors* for details on confounding factors) and account for them while two-sampling:

```
gptwosample -v -p -t -c x
```

but we do not want to account for confounders in this tutorial.

The output of the script shall be in the subfolder `./tutorial/`, so we add the output flag `-o ./tutorial/`:

```
gptwosample -v -p -t -o ./tutorial/
```

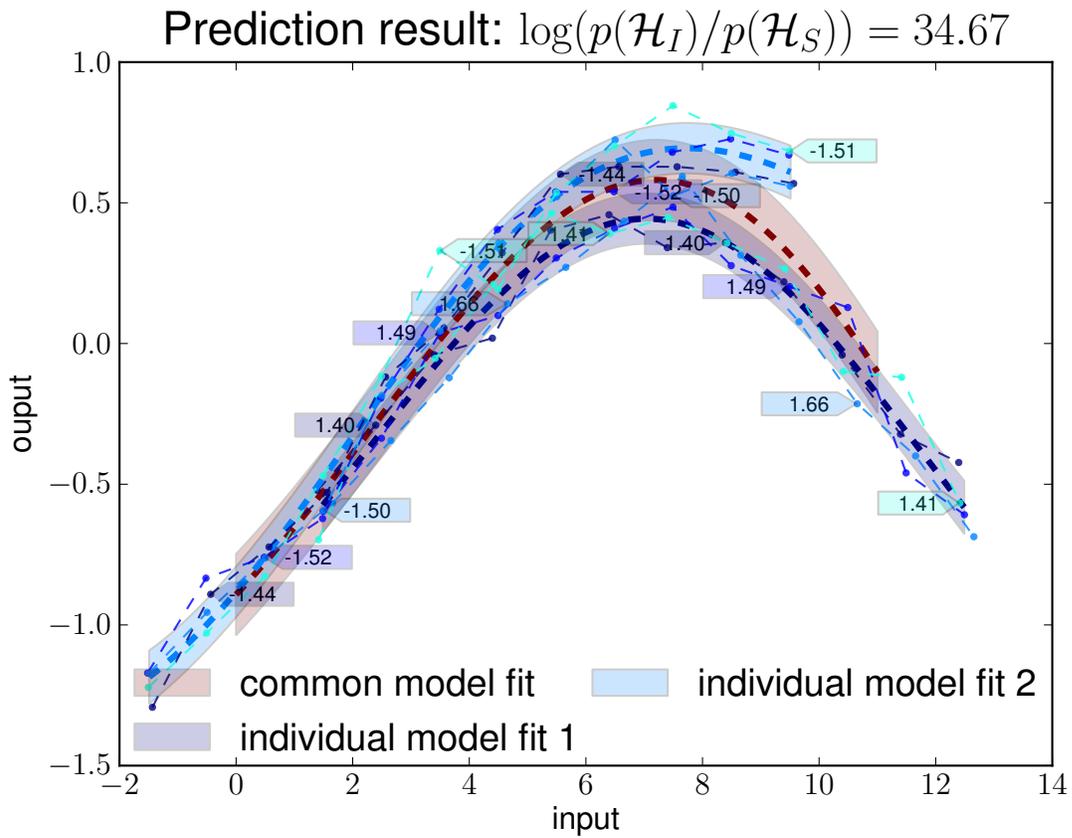
The script shall be run on the two toy condition files `ToyCondition{1,2}.csv` given in `examples/ToyCondition{1,2}.csv`. These files are non optional as this package is only for comparing two timeseries experiments to each other:

```
gptwosample -v -p -t -o ./tutorial/ examples/ToyCondition1.csv examples/ToyCondition2.csv
```

Note that the optional parameters could be collected together to give rise to a more compact call signature:

```
gptwosample -vpto tutorial examples/ToyCondition1.csv  
examples/ToyCondition2.csv
```

After hitting return the script runs `gptwosample` on every gene given in the `ToyCondition` files and plots each gene into `tutorial/plots/`. One example plot will look like:



The results are saved in the `results.csv`, which contains all predicted Bayes Factors and learnt covariance function parameters for all genes (*Result structure*).

For more tutorials and example files on how to use this package see `gptwosample/examples`.



# DEVELOPER

## 2.1 Package for using GPTwoSample

This module allows the user to compare two timelines with respect to differential expression.

It compares two timeseries against each other, depicting whether these two timeseries were more likely drawn from the same function, or from different ones. This prediction is defined by which covariance function `pygp.covar` you use.

Created on Jun 15, 2011

@author: Max Zwiessele, Oliver Stegle

```
class gptwosample.twosample.twosample.TwoSample(T, Y, covar_common=None, co-  
var_individual_1=None, co-  
var_individual_2=None)
```

Bases: `object`

Run GPTwoSample on given data.

### Parameters:

- *T* : TimePoints [n x r x t] [Samples x Replicates x Timepoints]
- *Y* : ExpressionMatrix [n x r x t x d] [Samples x Replicates x Timepoints x Genes]

### Fields:

- *T*: Time Points [n x r x t] [Samples x Replicates x Timepoints]
- *Y*: Expression [n x r x t x d] [Samples x Replicates x Timepoints x Genes]
- *X*: Confounders [nrt x 1+q] [SamplesReplicatesTimepoints x T+q]
- *lvm\_covariance*: GPLVM covaraince function used for confounder learning
- *n*: Samples
- *r*: Replicates
- *t*: Timepoints
- *d*: Genes
- *q*: Confounder Components

```
bayes_factors (likelihoods=None)  
get list of bayes_factors for all genes.
```

```
returns: bayes_factor for each gene in Y
```

**plot** (*xlabel='input', ylabel='ouput', title=None, interval\_indices=None, alpha=None, legend=True, replicate\_indices=None, shift=None, timeshift=False, \*args, \*\*kwargs*)  
iterate through all genes and plot

**predict\_likelihooods** (*T, Y, message='Predicting Likelihoods: ', messages=False, priors=None, \*\*kwargs*)  
Predict all likelihoods for all genes, given in Y

**parameters:**

**indices** `[[int]]` list (or array-like) for gene indices to predict, if None all genes will be predicted

**message:** `str` printing message

**kwargs:** `{...}` kwargs for `gptwosample.twosample.GPTwoSampleBase.predict_model_likelihooods`

**predict\_means\_variances** (*interpolation\_interval, indices=None, message='Predicting means and variances: ', \*args, \*\*kwargs*)  
Predicts means and variances for all genes given in Y for given interpolation\_interval

**set\_data** (*T, Y*)  
Set data by time T and expression matrix Y:

**Parameters:**

**T** `[real [n x r x t]]` All Timepoints with shape [Samples x Replicates x Timepoints]

**Y** `[real [n x r x t x d]]` All expression values given in the form: [Samples x Replicates x Timepoints x Genes]

**class** `gptwosample.confounder.confounder.TwoSampleConfounder` (*T, Y, q=4, lvm\_covariance=None, init='random', covar\_common=None, covar\_individual\_1=None, covar\_individual\_2=None*)

Bases: `gptwosample.twosample.twosample.TwoSample`

Run GPTwoSample on given Data

**Parameters:**

- **T** : TimePoints `[n x r x t]` [Samples x Replicates x Timepoints]
- **Y** : ExpressionMatrix `[n x r x t x d]` [Samples x Replicates x Timepoints x Genes]
- **q** : Number of Confounders to use
- **lvm\_covariance** : optional - set covariance to use in confounder learning
- **init** : [random, pca]

**Fields:**

- **T**: Time Points `[n x r x t]` [Samples x Replicates x Timepoints]
- **Y**: Expression `[n x r x t x d]` [Samples x Replicates x Timepoints x Genes]
- **X**: Confounders `[nrt x 1+q]` [SamplesReplicatesTimepoints x T+q]
- **lvm\_covariance**: GPLVM covaraince function used for confounder learning
- **n**: Samples
- **r**: Replicates
- **t**: Timepoints

- d: Genes
- q: Confounder Components

**initialize\_twosample\_covariance** (*covar\_common*=<function <lambda> at 0x107214230>, *covar\_individual\_1*=<function <lambda> at 0x1072141b8>, *covar\_individual\_2*=<function <lambda> at 0x107214758>)

initialize twosample covariance with function covariance(XX), where XX is a FixedCF with the learned confounder matrix.

default is SumCF([SqexpCFARD(1), FixedCF(self.K\_conf.copy()), BiasCF()])

**learn\_confounder\_matrix** (*ard\_indices*=None, *x*=None, *messages*=True, *gradient\_tolerance*=1e-12, *lvm\_dimension\_indices*=None, *gradient\_check*=False, *maxiter*=10000)

Learn confounder matrix with this model.

**Parameters:**

**x** [array-like] If you provided an own lvm\_covariance you have to specify the X to use within GPLVM

**lvm\_dimension\_indices** [[int]] If you specified an own lvm\_covariance you have to specify the dimension indices for GPLVM

**ard\_indices** [[indices]] If you provided an own lvm\_covariance, give the ard indices of the covariance here, to be able to use the correct hyperparameters for calculating the confounder covariance matrix.

**class** `gptwosample.twosample.twosample_base.TwoSampleShare` (*covar*, \**args*, \*\**kwargs*)

Bases: `gptwosample.twosample.twosample_base.TwoSampleBase`

This class provides comparison of two Timeline Groups to each other.

see `gptwosample.twosample.twosample_base.TwoSampleBase` for detailed description of provided methods.

**class** `gptwosample.twosample.twosample_base.TwoSampleSeparate` (*covar\_individual\_1*, *covar\_individual\_2*, *covar\_common*, \*\**kwargs*)

Bases: `gptwosample.twosample.twosample_base.TwoSampleBase`

This class provides comparison of two Timeline Groups to one another, including timeshifts in replicates, respectively.

see `gptwosample.twosample.twosample_base.TwoSampleBase` for detailed description of provided methods.

Note that this model will need one covariance function for each model, respectively!

**class** `gptwosample.twosample.twosample_base.TwoSampleBase` (*learn\_hyperparameters*=True, *priors*=None, *initial\_hyperparameters*=None, \*\**kwargs*)

Bases: `object`

TwoSampleBase object with the given covariance function covar.

**bayes\_factor** (*model\_likelihoods*=None)

Return the Bayes Factor for the given log marginal likelihoods *model\_likelihoods*

**Parameters:**

**model\_likelihoods** [{'individual': *the individual likelihoods*, 'common': *the common likelihoods*}]  
 The likelihoods calculated by predict\_model\_likelihoods(training\_data) for given training data training\_data.

**get\_data** (model='common model fit', index=None)  
 get inputs of model *model* with group index *index*. If index is None, the whole model group will be returned.

**get\_learned\_hyperparameters** ()  
 Returns learned hyperparameters in model structure, if already learned.

**get\_model\_likelihoods** ()  
 Returns all calculated likelihoods in model structure. If not calculated returns None in model structure.

**get\_predicted\_mean\_variance** ()  
 Get the predicted mean and variance as:

```
{'individual': {'mean': [pointwise mean], 'var': [pointwise variance]},
 'common': {'mean': [pointwise mean], 'var': [pointwise variance]}}
```

If not yet predicted it will return 'individual' and 'common' empty.

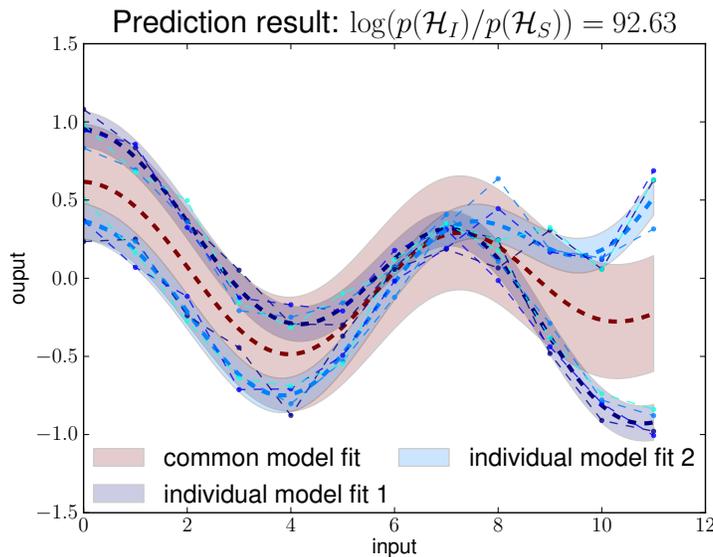
**plot** (xlabel='input', ylabel='ouput', title=None, interval\_indices=None, alpha=None, legend=True, replicate\_indices=None, shift=None, \*args, \*\*kwargs)  
 Plot the results given by last prediction.

Two Instance Plots of comparing two groups to each other:

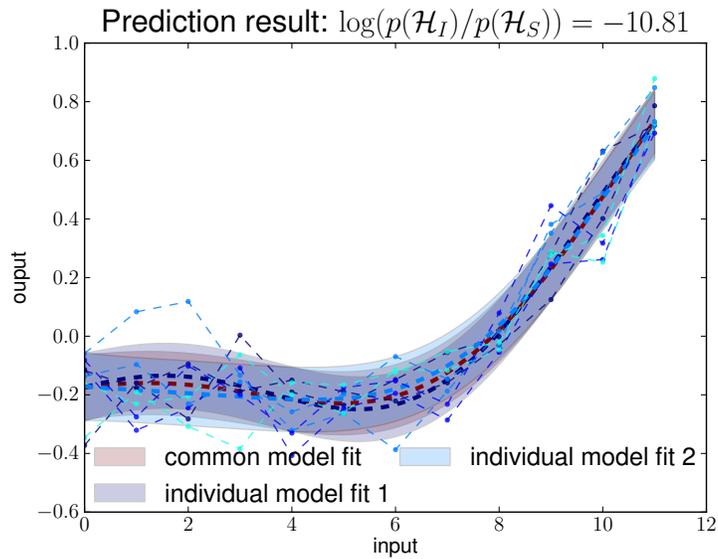
**Parameters:**

**twosample\_object** [gptwosample.twosample] GPTwoSample object, on which already 'predict' was called.

**Differential Groups:**



**Non-Differential Groups:**



**Returns:** Proper rectangles for use in `pylab.legend()`.

**predict\_mean\_variance** (*interpolation\_interval*, *hyperparams=None*, *interval\_indices={'common model fit': None, 'individual model fit': None}*, *\*args*, *\*\*kwargs*)

Predicts the mean and variance of both models. Returns:

```
{'individual': {'mean': [pointwise mean], 'var': [pointwise variance]},
 'common': {'mean': [pointwise mean], 'var': [pointwise variance]}}
```

**Parameters:**

**interpolation\_interval** [[double]] The interval of inputs, which shall be predicted

**hyperparams** [{ 'covar': logtheta, ...}] Default: learned hyperparameters. Hyperparams for the covariance function's prediction.

**interval\_indices** [{ 'common': [boolean], 'individual': [boolean]}] Indices in which to predict, for each group, respectively.

**predict\_model\_likelihoods** (*training\_data=None*, *interval\_indices={'common model fit': None, 'individual model fit': None}*, *\*args*, *\*\*kwargs*)

Predict the probabilities of the models (individual and common) to describe the data. It will optimize hyperparameters respectively.

**Parameters:**

**training\_data** [dict *training\_data*] The training data to learn from. Input are time-values and output are expression-values of e.g. a timeseries. If not given, training data must be given previously by `gptwosample.twosample.basic.set_data`.

**interval\_indices:** `gptwosample.data.data_base.get_model_structure()` interval indices, which assign data to individual or common model, respectively.

**args** [...] see `pygp.gpr.gp_base.GP`

**kwargs** [...] see `pygp.gpr.gp_base.GP`

**set\_data** (*training\_data*)

Set the data of prediction.

**Parameters:**

**training\_data** [dict training\_data] The training data to learn from. Input are time-values and output are expression-values of e.g. a timeseries.

Training data training\_data has following structure:

```
{'input' : {'group 1':[double] ... 'group n':[double]},  
 'output' : {'group 1':[double] ... 'group n':[double]}}
```

## 2.2 GPTwoSample plot

The easiest way to plot your results in an easy and convenient way.

### 2.2.1 Plot GPTwoSample predictions

Module for easy plotting of GPTwoSample results.

`gptwosample.plot.plot_basic.plot_results` plots training data, as well as sausage\_plots for a GPTwoSample experiment. You can give interval indices for plotting, if u chose

Created on Feb 10, 2011

@author: Max Zwiessele, Oliver Stegle

```
gptwosample.plot.plot_basic.plot_results(twosample_object,      xlabel='input',      yla-  
                                          bel='ouput', title=None, interval_indices=None,  
                                          alpha=None,          legend=True,        repli-  
                                          cate_indices=None,    shift=None,         *args,  
                                          **kwargs)
```

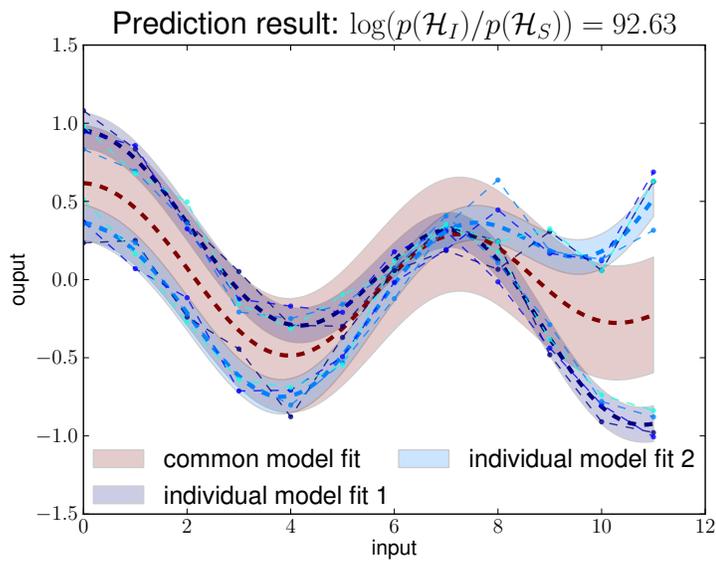
Plot the results given by last prediction.

Two Instance Plots of comparing two groups to each other:

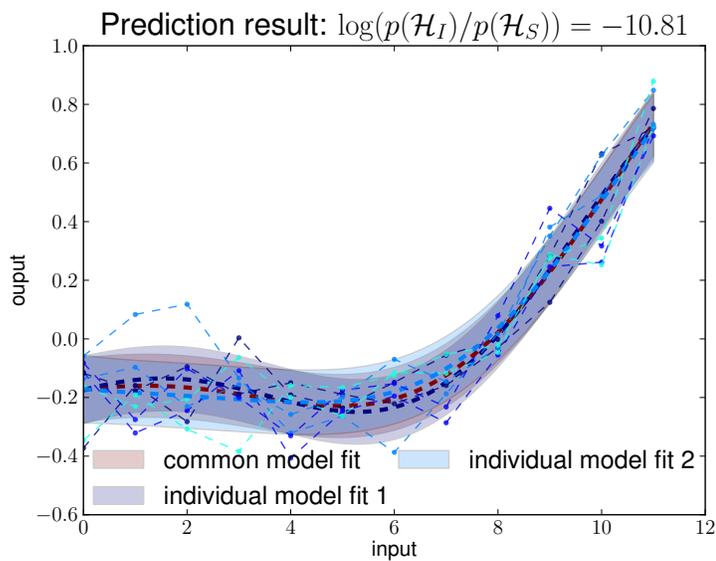
#### Parameters:

**twosample\_object** [`gptwosample.twosample`] GPTwoSample object, on which already 'predict' was called.

#### Differential Groups:



#### Non-Differential Groups:



**Returns:** Proper rectangles for use in `pylab.legend()`.

# .. automodule:: gptwosample.plot.interval # :members:

## 2.3 Package for data handling

Use this Package for easiest way to handle the data for GPTwoSample.

### 2.3.1 Data Structure Module

This Module is for easy access to data structures gptwosample works with.

Created on Mar 18, 2011

@author: Max Zwiessele

**exception** `gptwosample.data.data_base.DataStructureError` (\*args, \*\*kwargs)

Bases: `exceptions.TypeError`

Thrown, if `DataStructure` given does not fit. Training data `training_data` has following structure:

```
{input_id : {'group 1':[double] ... 'group n':[double]},
 output_id : {'group 1':[double] ... 'group n':[double]}}
```

`gptwosample.data.data_base.get_model_structure` (*individual=None, common=None*)

Returns the valid structure for model dictionaries, used in `gptwosample`. Make sure to use this method if you want to use the model structure in this package!

`gptwosample.data.data_base.get_training_data_structure` (*x1, x2, y1, y2*)

Get the structure for training data, given two inputs `x1` and `x2` with corresponding outputs `y1` and `y2`. Make sure, that replicates have to be tiled one after the other for proper resampling of data!

`gptwosample.data.data_base.has_model_structure` (*structure*)

Returns the valid structure for model dictionaries, used in `gptwosample`. Make sure to use this method if you want to use the model structure in this package!

### 2.3.2 Data IO tool

For convenient usage this module provides IO operations for data

Created on Jun 9, 2011

@author: Max Zwiessele, Oliver Stegle

`gptwosample.data.dataIO.get_data_from_csv` (*path\_to\_file, delimiter=',', count=-1, verbose=True, message='Reading File', fil=None*)

Return data from csv file with delimiter `delimiter` in form of a dictionary. Missing Values are all values `x` which cannot be converted `float(x)`

The file format has to fulfill following formation:

<i>arbitrary</i>	<i>x1</i>	<i>...</i>	<i>x1</i>
Gene Name 1	y1 replicate 1	...	y1 replicate 1
...	...	...	...
Gene Name 1	y1 replicate k1	...	y1 replicate k1
...			
Gene Name n	y1 replicate 1	...	y1 replicate 1
...	...	...	...
Gene Name n	y1 replicate kn	...	y1 replicate kn

Returns: {"input": [x1, ..., x1], "Gene Name 1": [y1 replicate 1, ... y1 replicate 1], ... , [y1 replicate k, ..., y1 replikate k]}

`gptwosample.data.dataIO.write_data_to_csv` (*data, path\_to\_file, header='GPTwoSample', delimiter=','*)

Write given data in `training_data_structure` (see `gptwosample.data.data_base` for details) into file for `path_to_file`.

#### Parameters:

**data** [dict] data to write in `training_data_structure`

**path\_to\_file** [String] The path to the file to write to

**header** [String] Name of the table

**delimiter** [character] delimiter for the csv file



# BIBLIOGRAPHY

- [Lawrence2004] Neil Lawrence, *Gaussian process latent variable models for visualisation of high dimensional data*, Advances in neural information processing systems, 2004
- [Stegle2010] Stegle, Oliver and Denby, Katherine J and Cooke, Emma J and Wild, David L and Ghahramani, Zoubin and Borgwardt, Karsten M, *A robust Bayesian two-sample test for detecting intervals of differential gene expression in microarray time series*, Journal of Computational Biology, 2010



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