fdasrsf Documentation

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CONTENTS

A python package for functional data analysis using the square root slope framework and curves using the square root velocity framework which performs pair-wise and group-wise alignment as well as modeling using functional component analysis and regression.

CHAPTER ONE

FUNCTIONAL ALIGNMENT

Group-wise function alignment using SRSF framework and Dynamic Programming

moduleauthor:: Derek Tucker <jdtuck@sandia.gov>

`time_warping.`**`align_fPCA`**(*f*, *time*, *num_comp=3*, *showplot=True*, *smoothdata=False*)

aligns a collection of functions while extracting principal components. The functions are aligned to the principal components

Parameters

- **f** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **num_comp** – number of fPCA components
- **showplot** – Shows plots of results using matplotlib (default = T)
- **smooth_data** (*bool*) – Smooth the data using a box filter (default = F)
- **sparam** (*double*) – Number of times to run box filter (default = 25)

Return type tuple of numpy array

Return fn aligned functions - numpy ndarray of shape (M,N) of N functions with M samples

Return qn aligned srvfs - similar structure to fn

Return q0 original srvf - similar structure to fn

Return mqn srvf mean or median - vector of length M

Return gam warping functions - similar structure to fn

Return q_pca srsf principal directions

Return f_pca functional principal directions

Return latent latent values

Return coef coefficients

Return U eigenvectors

Return orig_var Original Variance of Functions

Return amp_var Amplitude Variance

Return phase_var Phase Variance

`time_warping.`**`align_fPLS`**(*f*, *g*, *time*, *comps=3*, *showplot=True*, *smoothdata=False*, *delta=0.01*, *max_itr=100*)

This function aligns a collection of functions while performing principal least squares

Parameters

- **f** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples
- **g** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **comps** – number of fPLS components
- **showplot** – Shows plots of results using matplotlib (default = T)
- **smooth_data** (*bool*) – Smooth the data using a box filter (default = F)
- **delta** – gradient step size
- **max_itr** – maximum number of iterations

Return type tuple of numpy array

Return fn aligned functions - numpy ndarray of shape (M,N) of N

functions with M samples :return gn: aligned functions - numpy ndarray of shape (M,N) of N functions with M samples :return qfn: aligned srvfs - similar structure to fn :return qgn: aligned srvfs - similar structure to fn :return qf0: original srvf - similar structure to fn :return qg0: original srvf - similar structure to fn :return gam: warping functions - similar structure to fn :return wqf: srsf principal weight functions :return wqg: srsf principal weight functions :return wf: srsf principal weight functions :return wg: srsf principal weight functions :return cost: cost function value

time_warping.**srsf_align**(*f*, *time*, *method='mean'*, *omethod='DP'*, *showplot=True*, *smoothdata=False*, *parallel=False*, *lam=0.0*)

This function aligns a collection of functions using the elastic square-root slope (srsf) framework.

Parameters

- **f** – numpy ndarray of shape (M,N) of N functions with M samples
- **time** – vector of size M describing the sample points
- **method** – (string) warp calculate Karcher Mean or Median

(options = "mean" or "median") (default="mean") :param omethod: optimization method (DP, DP2, RBFGS) (default = DP) :param showplot: Shows plots of results using matplotlib (default = T) :param smoothdata: Smooth the data using a box filter (default = F) :param parallel: run in parallel (default = F) :param lam: controls the elasticity (default = 0) :type lam: double :type smoothdata: bool :type f: np.ndarray :type time: np.ndarray

Return type tuple of numpy array

Return fn aligned functions - numpy ndarray of shape (M,N) of N

functions with M samples :return qn: aligned srvfs - similar structure to fn :return q0: original srvf - similar structure to fn :return fmean: function mean or median - vector of length M :return mqn: srvf mean or median - vector of length M :return gam: warping functions - similar structure to fn :return orig_var: Original Variance of Functions :return amp_var: Amplitude Variance :return phase_var: Phase Variance

Examples >>> import tables >>> fun=tables.open_file("../Data/simu_data.h5") >>> f = fun.root.f[:] >>> f = f.transpose() >>> time = fun.root.time[:] >>> out = srsf_align(f,time)

time_warping.**srsf_align_pair**(*f*, *g*, *time*, *method='mean'*, *showplot=True*, *smoothdata=False*, *lam=0.0*)

This function aligns a collection of functions using the elastic square- root slope (srsf) framework.

Parameters

- **f** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples

- **g** – numpy ndarray of shape (M,N) of N functions with M samples
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **method** – (string) warp calculate Karcher Mean or Median (options = "mean" or "median") (default="mean")
- **showplot** – Shows plots of results using matplotlib (default = T)
- **smoothdata** (*bool*) – Smooth the data using a box filter (default = F)
- **lam** (*double*) – controls the elasticity (default = 0)

Return type tuple of numpy array

Return fn aligned functions - numpy ndarray of shape (M,N) of N functions with M samples

Return gn aligned functions - numpy ndarray of shape (M,N) of N functions with M samples

Return qfn aligned srvfs - similar structure to fn

Return qgn aligned srvfs - similar structure to fn

Return qf0 original srvf - similar structure to fn

Return qg0 original srvf - similar structure to fn

Return fmean f function mean or median - vector of length N

Return gmean g function mean or median - vector of length N

Return mqfn srvf mean or median - vector of length N

Return mqgn srvf mean or median - vector of length N

Return gam warping functions - similar structure to fn

CHAPTER

TWO

FUNCTIONAL PRINCIPAL COMPONENT ANALYSIS

Vertical and Horizontal Functional Principal Component Analysis using SRSF

moduleauthor:: Derek Tucker <jdtuck@sandia.gov>

`fPCA.`**`horizfPCA`**(*gam*, *time*, *no=2*, *showplot=True*)

This function calculates horizontal functional principal component analysis on aligned data

Parameters

- **gam** – numpy ndarray of shape (M,N) of N warping functions
- **time** – vector of size M describing the sample points
- **no** (*int*) – number of components to extract (default = 2)
- **showplot** (*bool*) – Shows plots of results using matplotlib (default = T)

Return type tuple of numpy ndarray

Return q_pca srsf principal directions

Return f_pca functional principal directions

Return latent latent values

Return coef coefficients

Return U eigenvectors

`fPCA.`**`jointfPCA`**(*fn*, *time*, *qn*, *q0*, *gam*, *no=2*, *showplot=True*)

This function calculates joint functional principal component analysis on aligned data

Parameters

- **fn** – numpy ndarray of shape (M,N) of N aligned functions with M samples
- **time** – vector of size N describing the sample points
- **qn** – numpy ndarray of shape (M,N) of N aligned SRSF with M samples
- **no** (*int*) – number of components to extract (default = 2)
- **showplot** (*bool*) – Shows plots of results using matplotlib (default = T)

Return type tuple of numpy ndarray

Return q_pca srsf principal directions

Return f_pca functional principal directions

Return latent latent values

Return coef coefficients

Return U eigenvectors

fPCA.**vertfPCA**(*fn*, *time*, *qn*, *no=2*, *showplot=True*)

This function calculates vertical functional principal component analysis on aligned data

Parameters

- **fn** – numpy ndarray of shape (M,N) of N aligned functions with M samples
- **time** – vector of size N describing the sample points
- **qn** – numpy ndarray of shape (M,N) of N aligned SRSF with M samples
- **no** (*int*) – number of components to extract (default = 2)
- **showplot** (*bool*) – Shows plots of results using matplotlib (default = T)

Return type tuple of numpy ndarray

Return q_pca srsf principal directions

Return f_pca functional principal directions

Return latent latent values

Return coef coefficients

Return U eigenvectors

CHAPTER THREE

ELASTIC FUNCTIONAL BOXPLOTS

Elastic Functional Boxplots

moduleauthor:: Derek Tucker <jdtuck@sandia.gov>

`boxplots.ampbox`(*ft*, *f_median*, *qt*, *q_median*, *time*, *alpha=0.05*, *k_a=1*)

This function constructs the amplitude boxplot using the elastic square-root slope (srsf) framework.

Parameters

- **ft** – numpy ndarray of shape (M,N) of N functions with M samples
- **f_median** – vector of size M describing the median
- **qt** – numpy ndarray of shape (M,N) of N srsf functions with M samples
- **q_median** – vector of size M describing the srsf median
- **time** – vector of size M describing the time
- **alpha** – quantile value (e.g.,=.05, i.e., 95%)
- **k_a** – scalar for outlier cutoff (e.g.,=1)

Return type tuple of numpy array

Return fn aligned functions - numpy ndarray of shape (M,N) of N

functions with M samples :return Q1: First quartile :return Q3: Second quartile :return Q1a: First quantile based on alpha :return Q3a: Second quantile based on alpha :return minn: minimum extreme function :return maxx: maximum extreme function :return outlier_index: indexes of outlier functions :return f_median: median function :return q_median: median srsf :return plt: surface plot mesh

`boxplots.phbox`(*gam*, *time*, *alpha=0.05*, *k_a=1*)

This function constructs phase boxplot for functional data using the elastic square-root slope (srsf) framework.

Parameters

- **gam** – numpy ndarray of shape (M,N) of N warping functions with M samples
- **alpha** – quantile value (e.g.,=.05, i.e., 95%)
- **k_a** – scalar for outlier cutoff (e.g.,=1)

Return type tuple of numpy array

Return fn aligned functions - numpy ndarray of shape (M,N) of N

functions with M samples :return Q1: First quartile :return Q3: Second quartile :return Q1a: First quantile based on alpha :return Q3a: Second quantile based on alpha :return minn: minimum extreme function :return maxx: maximum extreme function :return outlier_index: indexes of outlier functions :return median_x: median warping function :return psi_median: median srsf of warping function :return plt: surface plot mesh

CHAPTER

FOUR

GAUSSIAN GENERATIVE MODELS

Gaussian Model of functional data

moduleauthor:: Derek Tucker <jdtuck@sandia.gov>

`gauss_model.`**`gauss_model`**(*fn*, *time*, *qn*, *gam*, *n=1*, *sort_samples=False*)

This function models the functional data using a Gaussian model extracted from the principal components of the srvfs

Parameters

- **fn** (*np.ndarray*) – numpy ndarray of shape (M,N) of N aligned functions with M samples
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **qn** (*np.ndarray*) – numpy ndarray of shape (M,N) of N aligned srvfs with M samples
- **gam** (*np.ndarray*) – warping functions
- **n** (*integer*) – number of random samples
- **sort_samples** (*bool*) – sort samples (default = T)

Return type tuple of numpy array

Return fs random aligned samples

Return gams random warping functions

Return ft random samples

`gauss_model.`**`joint_gauss_model`**(*fn*, *time*, *qn*, *gam*, *q0*, *n=1*, *no=3*)

This function models the functional data using a joint Gaussian model extracted from the principal components of the srsfs

Parameters

- **fn** (*np.ndarray*) – numpy ndarray of shape (M,N) of N aligned functions with M samples
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **qn** (*np.ndarray*) – numpy ndarray of shape (M,N) of N aligned srsfs with M samples
- **gam** (*np.ndarray*) – warping functions
- **q0** – numpy ndarray of shape (M,N) of N unaligned srsfs with samples
- **n** (*integer*) – number of random samples
- **n** – number of principal components (default = 3)

Return type tuple of numpy array

Return fs random aligned samples

Return gams random warping functions

Return ft random samples

CHAPTER

FIVE

FUNCTIONAL PRINCIPAL LEAST SQUARES

Partial Least Squares using SVD

moduleauthor:: Derek Tucker <jdtuck@sandia.gov>

`fPLS.pls_svd(time, qf, qg, no, alpha=0.0)`

This function computes the partial least squares using SVD

Parameters

- **time** – vector describing time samples
- **qf** – numpy ndarray of shape (M,N) of N functions with M samples
- **qg** – numpy ndarray of shape (M,N) of N functions with M samples
- **no** – number of components
- **alpha** – amount of smoothing (Default = 0.0 i.e., none)

Return type numpy ndarray

Return wqf f weight function

Return wqg g weight function

Return alpha smoothing value

Return values singular values

CHAPTER SIX

ELASTIC REGRESSION

Warping Invariant Regression using SRSF

moduleauthor:: Derek Tucker <jdtuck@sandia.gov>

`regression.`**`elastic_logistic`**(*f*, *y*, *time*, *B=None*, *df=20*, *max_itr=20*, *cores=-1*, *smooth=False*)

This function identifies a logistic regression model with phase-variablity using elastic methods

Parameters

- **f** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy array of labels (1/-1)
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **B** – optional matrix describing Basis elements
- **df** – number of degrees of freedom B-spline (default 20)
- **max_itr** – maximum number of iterations (default 20)
- **cores** – number of cores for parallel processing (default all)

Return type tuple of numpy array

Return alpha alpha parameter of model

Return beta beta(t) of model

Return fn aligned functions - numpy ndarray of shape (M,N) of M

functions with N samples :return qn: aligned srvfs - similar structure to fn :return gamma: calculated warping functions :return q: original training SRSFs :return B: basis matrix :return b: basis coefficients :return Loss: logistic loss

`regression.`**`elastic_mlogistic`**(*f*, *y*, *time*, *B=None*, *df=20*, *max_itr=20*, *cores=-1*, *delta=0.01*, *parallel=True*, *smooth=False*)

This function identifies a multinomial logistic regression model with phase-variablity using elastic methods

Parameters

- **f** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy array of labels {1,2,...,m} for m classes
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **B** – optional matrix describing Basis elements
- **df** – number of degrees of freedom B-spline (default 20)
- **max_itr** – maximum number of iterations (default 20)

- **cores** – number of cores for parallel processing (default all)

Return type tuple of numpy array

Return alpha alpha parameter of model

Return beta beta(t) of model

Return fn aligned functions - numpy ndarray of shape (M,N) of N

functions with M samples :return qn: aligned srvfs - similar structure to fn :return gamma: calculated warping functions :return q: original training SRSFs :return B: basis matrix :return b: basis coefficients :return Loss: logistic loss

regression.**elastic_prediction**(*f*, *time*, *model*, *y=None*, *smooth=False*)

This function performs prediction from an elastic regression model with phase-variablity

Parameters

- **f** – numpy ndarray of shape (M,N) of N functions with M samples
- **time** – vector of size M describing the sample points
- **model** – indentified model from elastic_regression
- **y** – truth, optional used to calculate SSE

Return type tuple of numpy array

Return alpha alpha parameter of model

Return beta beta(t) of model

Return fn aligned functions - numpy ndarray of shape (M,N) of N

functions with M samples :return qn: aligned srvfs - similar structure to fn :return gamma: calculated warping functions :return q: original training SRSFs :return B: basis matrix :return b: basis coefficients :return SSE: sum of squared error

regression.**elastic_regression**(*f*, *y*, *time*, *B=None*, *lam=0*, *df=20*, *max_itr=20*, *cores=-1*, *smooth=False*)

This function identifies a regression model with phase-variablity using elastic methods

Parameters

- **f** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy array of N responses
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **B** – optional matrix describing Basis elements
- **lam** – regularization parameter (default 0)
- **df** – number of degrees of freedom B-spline (default 20)
- **max_itr** – maximum number of iterations (default 20)
- **cores** – number of cores for parallel processing (default all)

Return type tuple of numpy array

Return alpha alpha parameter of model

Return beta beta(t) of model

Return fn aligned functions - numpy ndarray of shape (M,N) of M functions with N samples :return qn: aligned srvfs - similar structure to fn :return gamma: calculated warping functions :return q: original training SRSFs :return B: basis matrix :return b: basis coefficients :return SSE: sum of squared error

regression.**logistic_warp**(*beta*, *time*, *q*, *y*)
calculates optimal warping for function logistic regression

Parameters

- **beta** – numpy ndarray of shape (M,N) of N functions with M samples
- **time** – vector of size N describing the sample points
- **q** – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy ndarray of shape (1,N) responses

Return type numpy array

Return gamma warping function

regression.**logit_gradient**(*b*, *X*, *y*)
calculates gradient of the logistic loss

Parameters

- **b** – numpy ndarray of shape (M,N) of N functions with M samples
- **X** – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy ndarray of shape (1,N) responses

Return type numpy array

Return grad gradient of logisitc loss

regression.**logit_hessian**(*s*, *b*, *X*, *y*)
calculates hessian of the logistic loss

Parameters

- **s** – numpy ndarray of shape (M,N) of N functions with M samples
- **b** – numpy ndarray of shape (M,N) of N functions with M samples
- **X** – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy ndarray of shape (1,N) responses

Return type numpy array

Return out hessian of logistic loss

regression.**logit_loss**(*b*, *X*, *y*)
logistic loss function, returns Sum{-log(phi(t))}

Parameters

- **b** – numpy ndarray of shape (M,N) of N functions with M samples
- **X** – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy ndarray of shape (1,N) of N responses

Return type numpy array

Return out loss value

regression.**mlogit_gradient**(*b*, *X*, *Y*)

calculates gradient of the multinomial logistic loss

Parameters

- **b** – numpy ndarray of shape (M,N) of N functions with M samples
- **X** – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy ndarray of shape (1,N) responses

Return type numpy array

Return grad gradient

regression.**mlogit_loss**(*b*, *X*, *Y*)

calculates multinomial logistic loss (negative log-likelihood)

Parameters

- **b** – numpy ndarray of shape (M,N) of N functions with M samples
- **X** – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy ndarray of shape (1,N) responses

Return type numpy array

Return nll negative log-likelihood

regression.**mlogit_warp_grad**(*alpha*, *beta*, *time*, *q*, *y*, *max_itr=8000*, *tol=1e-10*, *delta=0.008*, *display=0*)

calculates optimal warping for functional multinomial logistic regression

Parameters

- **alpha** – scalar
- **beta** – numpy ndarray of shape (M,N) of N functions with M samples
- **time** – vector of size M describing the sample points
- **q** – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy ndarray of shape (1,N) responses
- **max_itr** – maximum number of iterations (Default=8000)
- **tol** – stopping tolerance (Default=1e-10)
- **delta** – gradient step size (Default=0.008)
- **display** – display iterations (Default=0)

Return type tuple of numpy array

Return gam_old warping function

regression.**phi**(*t*)

calculates logistic function, returns 1 / (1 + exp(-t))

Parameters **t** – scalar

Return type numpy array

Return out return value

regression.**regression_warp**(*beta*, *time*, *q*, *y*, *alpha*)

calculates optimal warping for function linear regression

Parameters

- **beta** – numpy ndarray of shape (M,N) of M functions with N samples
- **time** – vector of size N describing the sample points
- **q** – numpy ndarray of shape (M,N) of M functions with N samples
- **y** – numpy ndarray of shape (1,N) of M functions with N samples

responses :param alpha: numpy scalar

Return type numpy array

Return gamma_new warping function

CHAPTER SEVEN

ELASTIC PRINCIPAL COMPONENT REGRESSION

Warping PCR Invariant Regression using SRSF

moduleauthor:: Derek Tucker <jdtuck@sandia.gov>

`pcr_regression.elastic_lpcr_regression`(*f*, *y*, *time*, *pca_method='combined'*, *no=5*, *smooth_data=False*, *sparam=25*)

This function identifies a logistic regression model with phase-variability using elastic pca

Parameters

- **f** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy array of N responses
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **pca_method** – string specifing pca method (options = "combined", "vert", or "horiz", default = "combined")
- **no** – scalar specify number of principal components (default=5)
- **smooth_data** – smooth data using box filter (default = F)
- **sparam** – number of times to apply box filter (default = 25)

Return type tuple of numpy array

Return alpha alpha parameter of model

Return b regressor vector

Return y response vector

Return warp_data alignment object from srsf_align

Return pca fpca object from corresponding pca method

Return Loss logistic loss

Return pca.method string of pca method

`pcr_regression.elastic_mlpcr_regression`(*f*, *y*, *time*, *pca_method='combined'*, *no=5*, *smooth_data=False*, *sparam=25*)

This function identifies a logistic regression model with phase-variability using elastic pca

Parameters

- **f** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy array of N responses
- **time** (*np.ndarray*) – vector of size M describing the sample points

- **pca_method** – string specifing pca method (options = "combined", "vert", or "horiz", default = "combined")
- **no** – scalar specify number of principal components (default=5)
- **smooth_data** – smooth data using box filter (default = F)
- **sparam** – number of times to apply box filter (default = 25)

Return type tuple of numpy array

Return alpha alpha parameter of model

Return b regressor vector

Return y response vector

Return warp_data alignment object from srsf_align

Return pca fpca object from corresponding pca method

Return Loss logistic loss

Return pca.method string of pca method

`pcr_regression.`**`elastic_pcr_regression`**(*f*, *y*, *time*, *pca_method='combined'*, *no=5*, *smooth_data=False*, *sparam=25*, *parallel=False*, *C=None*)

This function identifies a regression model with phase-variability using elastic pca

Parameters

- **f** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples
- **y** – numpy array of N responses
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **pca_method** – string specifing pca method (options = "combined", "vert", or "horiz", default = "combined")
- **no** – scalar specify number of principal components (default=5)
- **smooth_data** – smooth data using box filter (default = F)
- **sparam** – number of times to apply box filter (default = 25)
- **parallel** – run in parallel (default = F)
- **C** – scale balance parameter for combined method (default = None)

Return type tuple of numpy array

Return alpha alpha parameter of model

Return b regressor vector

Return y response vector

Return warp_data alignment object from srsf_align

Return pca fpca object from corresponding pca method

Return SSE sum of squared errors

Return pca.method string of pca method

CHAPTER

EIGHT

ELASTIC FUNCTIONAL TOLERANCE BOUNDS

Functional Tolerance Bounds using SRSF

moduleauthor:: Derek Tucker <jdtuck@sandia.gov>

`tolerance.`**`bootTB`**(*f*, *time*, *a=0.5*, *p=0.99*, *B=500*, *no=5*, *parallel=True*)

This function computes tolerance bounds for functional data containing phase and amplitude variation using bootstrap sampling

Parameters

- **f** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **a** – confidence level of tolerance bound (default = 0.05)
- **p** – coverage level of tolerance bound (default = 0.99)
- **B** – number of bootstrap samples (default = 500)
- **no** – number of principal components (default = 5)
- **parallel** – enable parallel processing (default = T)

Return type tuple of boxplot objects

Return amp amplitude tolerance bounds

Return ph phase tolerance bounds

`tolerance.`**`mvtol_region`**(*x*, *alpha*, *P*, *B*)

Krishnamoorthy, K. and Mondal, S. (2006), Improved Tolerance Factors for Multivariate Normal Distributions, Communications in Statistics - Simulation and Computation, 35, 461–478.

Parameters

- **x** – (M,N) matrix defining N variables of M samples
- **alpha** – confidence level
- **P** – coverage level
- **B** – number of bootstrap samples

Return type double

Return tol tolerance factor

`tolerance.`**`pcaTB`**(*f*, *time*, *a=0.5*, *p=0.99*, *no=5*, *parallel=True*)

This function computes tolerance bounds for functional data containing phase and amplitude variation using fPCA

Parameters

- **f** (*np.ndarray*) – numpy ndarray of shape (M,N) of N functions with M samples
- **time** (*np.ndarray*) – vector of size M describing the sample points
- **a** – confidence level of tolerance bound (default = 0.05)
- **p** – coverage level of tolerance bound (default = 0.99)
- **no** – number of principal components (default = 5)
- **parallel** – enable parallel processing (default = T)

Return type tuple of boxplot objects

Return warp alignment data from time_warping

Return pca functional pca from jointFPCA

Return tol tolerance factor

`tolerance.`**randn**(*d0*, *d1*, *...*, *dn*)

Return a sample (or samples) from the "standard normal" distribution.

If positive, int_like or int-convertible arguments are provided, *randn* generates an array of shape `(d0, d1, ..., dn)`, filled with random floats sampled from a univariate "normal" (Gaussian) distribution of mean 0 and variance 1 (if any of the d_i are floats, they are first converted to integers by truncation). A single float randomly sampled from the distribution is returned if no argument is provided.

This is a convenience function. If you want an interface that takes a tuple as the first argument, use *numpy.random.standard_normal* instead.

d0, d1, ..., dn [int, optional] The dimensions of the returned array, should be all positive. If no argument is given a single Python float is returned.

Z [ndarray or float] A `(d0, d1, ..., dn)`-shaped array of floating-point samples from the standard normal distribution, or a single such float if no parameters were supplied.

standard_normal : Similar, but takes a tuple as its argument.

For random samples from $N(\mu, \sigma^2)$, use:

`sigma * np.random.randn(...) + mu`

```
>>> np.random.randn()
2.1923875335537315 #random
```

Two-by-four array of samples from N(3, 6.25):

```
>>> 2.5 * np.random.randn(2, 4) + 3
array([[-4.49401501,  4.00950034, -1.81814867,  7.29718677],  #random
       [ 0.39924804,  4.68456316,  4.99394529,  4.84057254]]) #random
```

`tolerance.`**rwishart**(*df*, *p*)

Parameters

- **df** – degree of freedom
- **p** – number of dimensions

Return type double

Return R matrix

CHAPTER

NINE

SRVF GEODESIC COMPUTATION

geodesic calculation for SRVF (curves) open and closed)

moduleauthor:: Derek Tucker <jdtuck@sandia.gov>

`geodesic.`**`back_parallel_transport`**(*u1*, *alpha*, *basis*, *T=100*, *k=5*)

backwards parallel translates q1 and q2 along manifold

Parameters

- **`u1`** – numpy ndarray of shape (2,M) of M samples
- **`alpha`** – numpy ndarray of shape (2,M) of M samples
- **`basis`** – list numpy ndarray of shape (2,M) of M samples
- **`T`** – Number of samples of curve (Default = 100)
- **`k`** – number of samples along path (Default = 5)

Return type numpy ndarray

Return utilde translated vector

`geodesic.`**`calc_alphadot`**(*alpha*, *basis*, *T=100*, *k=5*)

calculates derivative along the path alpha

Parameters

- **`alpha`** – numpy ndarray of shape (2,M) of M samples
- **`basis`** – list of numpy ndarray of shape (2,M) of M samples
- **`T`** – Number of samples of curve (Default = 100)
- **`k`** – number of samples along path (Default = 5)

Return type numpy ndarray

Return alphadot derivative of alpha

`geodesic.`**`calculate_energy`**(*alphadot*, *T=100*, *k=5*)

calculates energy along path

Parameters

- **`alphadot`** – numpy ndarray of shape (2,M) of M samples
- **`T`** – Number of samples of curve (Default = 100)
- **`k`** – number of samples along path (Default = 5)

Return type numpy scalar

Return E energy

geodesic.**calculate_gradE**(*u*, *utilde*, *T=100*, *k=5*)
calculates gradient of energy along path

Parameters

- **u** – numpy ndarray of shape (2,M) of M samples
- **utilde** – numpy ndarray of shape (2,M) of M samples
- **T** – Number of samples of curve (Default = 100)
- **k** – number of samples along path (Default = 5)

Return type numpy scalar

Return gradE gradient of energy

Return normgradE norm of gradient of energy

geodesic.**cov_integral**(*alpha*, *alphadot*, *basis*, *T=100*, *k=5*)
Calculates covariance along path alpha

Parameters

- **alpha** – numpy ndarray of shape (2,M) of M samples (first curve)
- **alphadot** – numpy ndarray of shape (2,M) of M samples
- **basis** – list numpy ndarray of shape (2,M) of M samples
- **T** – Number of samples of curve (Default = 100)
- **k** – number of samples along path (Default = 5)

Return type numpy ndarray

Return u covariance

geodesic.**find_basis_normal_path**(*alpha*, *k=5*)
computes orthonormalized basis vectors to the normal space at each of the k points (q-functions) of the path alpha

Parameters

- **alpha** – numpy ndarray of shape (2,M) of M samples (path)
- **k** – number of samples along path (Default = 5)

Return type numpy ndarray

Return basis basis vectors along the path

geodesic.**geod_dist_path_strt**(*beta*, *k=5*)
calculate geodisc distance for path straightening

Parameters

- **beta** – numpy ndarray of shape (2,M) of M samples
- **k** – number of samples along path (Default = 5)

Return type numpy scalar

Return dist geodesic distance

geodesic.**geod_sphere**(*beta1*, *beta2*, *k=5*)
This function caluclates the geodecis between open curves beta1 and beta2 with k steps along path

Parameters

- **beta1** – numpy ndarray of shape (2,M) of M samples
- **beta2** – numpy ndarray of shape (2,M) of M samples
- **k** – number of samples along path (Default = 5)

Return type numpy ndarray

Return dist geodesic distance

Return path geodesic path

Return O rotation matrix

geodesic.**init_path_geod**(*beta1*, *beta2*, *T=100*, *k=5*)

Initializes a path in cal{C}. beta1, beta2 are already standardized curves. Creates a path from beta1 to beta2 in shape space, then projects to the closed shape manifold.

Parameters

- **beta1** – numpy ndarray of shape (2,M) of M samples (first curve)
- **beta2** – numpy ndarray of shape (2,M) of M samples (end curve)
- **T** – Number of samples of curve (Default = 100)
- **k** – number of samples along path (Default = 5)

Return type numpy ndarray

Return alpha a path between two q-functions

Return beta a path between two curves

Return O rotation matrix

geodesic.**init_path_rand**(*beta1*, *beta_mid*, *beta2*, *T=100*, *k=5*)

Initializes a path in cal{C}. beta1, beta_mid beta2 are already standardized curves. Creates a path from beta1 to beta_mid to beta2 in shape space, then projects to the closed shape manifold.

Parameters

- **beta1** – numpy ndarray of shape (2,M) of M samples (first curve)
- **betamid** – numpy ndarray of shape (2,M) of M samples (mid curve)
- **beta2** – numpy ndarray of shape (2,M) of M samples (end curve)
- **T** – Number of samples of curve (Default = 100)
- **k** – number of samples along path (Default = 5)

Return type numpy ndarray

Return alpha a path between two q-functions

Return beta a path between two curves

Return O rotation matrix

geodesic.**path_straightening**(*beta1*, *beta2*, *betamid*, *init='rand'*, *T=100*, *k=5*)

Perform path straigtening to find geodesic between two shapes in either the space of closed curves or the space of affine standardized curves. This algorithm follows the steps outlined in section 4.6 of the manuscript.

Parameters

- **beta1** – numpy ndarray of shape (2,M) of M samples (first curve)

- **beta2** – numpy ndarray of shape (2,M) of M samples (end curve)
- **betamid** – numpy ndarray of shape (2,M) of M samples (mid curve Default = NULL, only needed for init "rand")
- **init** – initilizae path geodesic or random (Default = "rand")
- **T** – Number of samples of curve (Default = 100)
- **k** – number of samples along path (Default = 5)

Return type numpy ndarray

Return dist geodesic distance

Return path geodesic path

Return pathsqnc geodesic path sequence

Return E energy

geodesic.**update_path**(*alpha*, *beta*, *gradE*, *delta*, *T=100*, *k=5*)
Update the path along the direction -gradE

Parameters

- **alpha** – numpy ndarray of shape (2,M) of M samples
- **beta** – numpy ndarray of shape (2,M) of M samples
- **gradE** – numpy ndarray of shape (2,M) of M samples
- **delta** – gradient paramenter
- **T** – Number of samples of curve (Default = 100)
- **k** – number of samples along path (Default = 5)

Return type numpy scalar

Return alpha updated path of srvfs

Return beta updated path of curves

CHAPTER

TEN

UTILITY FUNCTIONS

Utility functions for SRSF Manipulations

moduleauthor:: Derek Tucker <jdtuck@sandia.gov>

`utility_functions.`**`SqrtMean`**(*gam*)
calculates the srsf of warping functions with corresponding shooting vectors

Parameters **`gam`** – numpy ndarray of shape (M,N) of M warping functions with N samples

Return type 2 numpy ndarray and vector

Return mu Karcher mean psi function

Return gam_mu vector of dim N which is the Karcher mean warping function

Return psi numpy ndarray of shape (M,N) of M SRSF of the warping functions

Return vec numpy ndarray of shape (M,N) of M shooting vectors

`utility_functions.`**`SqrtMeanInverse`**(*gam*)
finds the inverse of the mean of the set of the diffeomorphisms gamma

Parameters **`gam`** – numpy ndarray of shape (M,N) of M warping functions with N samples

Return type vector

Return gamI inverse of gam

`utility_functions.`**`SqrtMedian`**(*gam*)
calculates the median srsf of warping functions with corresponding shooting vectors

Parameters **`gam`** – numpy ndarray of shape (M,N) of M warping functions with N samples

Return type 2 numpy ndarray and vector

Return gam_median Karcher median warping function

Return psi_meidan vector of dim N which is the Karcher median srsf function

Return psi numpy ndarray of shape (M,N) of M SRSF of the warping functions

Return vec numpy ndarray of shape (M,N) of M shooting vectors

`utility_functions.`**`cumtrapzmid`**(*x*, *y*, *c*, *mid*)
cumulative trapezoidal numerical integration taken from midpoint

Parameters

- **`x`** – vector of size N describing the time samples
- **`y`** – vector of size N describing the function
- **`c`** – midpoint

- **mid** – midpiont location

Return type vector

Return fa cumulative integration

`utility_functions.diffop(n, binsize=1)`
Creates a second order differential operator

Parameters

- **n** – dimension
- **binsize** – dx (default = 1)

Return type numpy ndarray

Return m matrix describing differential operator

`utility_functions.elastic_distance(f1, f2, time, lam=0.0)`
" calculates the distances between function, where f1 is aligned to f2. In other words calculates the elastic distances

Parameters

- **f1** – vector of size N
- **f2** – vector of size N
- **time** – vector of size N describing the sample points
- **lam** – controls the elasticity (default = 0.0)

Return type scalar

Return Dy amplitude distance

Return Dx phase distance

`utility_functions.f_K_fold(Nobs, K=5)`
generates sample indices for K-fold cross validation

:param Nobs number of observations :param K number of folds

Return type numpy ndarray

Return train train indexes (Nobs*(K-1)/K X K)

Return test test indexes (Nobs*(1/K) X K)

`utility_functions.f_to_srsf(f, time, smooth=False)`
converts f to a square-root slope function (SRSF)

Parameters

- **f** – vector of size N samples
- **time** – vector of size N describing the sample points

Return type vector

Return q srsf of f

`utility_functions.geigen(Amat, Bmat, Cmat)`
generalized eigenvalue problem of the form

max tr L'AM / sqrt(tr L'BL tr M'CM) w.r.t. L and M

:param Amat numpy ndarray of shape (M,N) :param Bmat numpy ndarray of shape (M,N) :param Bmat numpy ndarray of shape (M,N)

Return type numpy ndarray

Return values eigenvalues

Return Lmat left eigenvectors

Return Mmat right eigenvectors

`utility_functions.`**`gradient_spline`**(*time*, *f*, *smooth=False*)

This function takes the gradient of f using b-spline smoothing

Parameters

- **`time`** – vector of size N describing the sample points
- **`f`** – numpy ndarray of shape (M,N) of M functions with N samples
- **`smooth`** – smooth data (default = F)

Return type tuple of numpy ndarray

Return f0 smoothed functions functions

Return g first derivative of each function

Return g2 second derivative of each function

`utility_functions.`**`innerprod_q`**(*time*, *q1*, *q2*)

calculates the innerproduct between two srsfs

:param time vector descrbing time samples :param q1 vector of srsf 1 :param q2 vector of srsf 2

Return type scalar

Return val inner product value

`utility_functions.`**`invertGamma`**(*gam*)

finds the inverse of the diffeomorphism gamma

Parameters **`gam`** – vector describing the warping function

Return type vector

Return gamI inverse of gam

`utility_functions.`**`optimum_reparam`**(*q1*, *time*, *q2*, *method='DP'*, *lam=0.0*, *f1o=0.0*, *f2o=0.0*)

calculates the warping to align srsf q2 to q1

Parameters

- **`q1`** – vector of size N or array of NxM samples of first SRSF
- **`time`** – vector of size N describing the sample points
- **`q2`** – vector of size N or array of NxM samples samples of second SRSF
- **`method`** – method to apply optimzation (default="DP") options are "DP", "DP2" and "RBFGS"
- **`lam`** – controls the amount of elasticity (default = 0.0)

Return type vector

Return gam describing the warping function used to align q2 with q1

utility_functions.**optimum_reparam_pair**(*q*, *time*, *q1*, *q2*, *lam=0.0*)
calculates the warping to align srsf pair q1 and q2 to q

Parameters

- **q** – vector of size N or array of NxM samples of first SRSF
- **time** – vector of size N describing the sample points
- **q1** – vector of size N or array of NxM samples samples of second SRSF
- **q2** – vector of size N or array of NxM samples samples of second SRSF
- **lam** – controls the amount of elasticity (default = 0.0)

Return type vector

Return gam describing the warping function used to align q2 with q1

utility_functions.**outlier_detection**(*q*, *time*, *mq*, *k=1.5*)
calculates outlier's using geodesic distances of the SRSFs from the median

Parameters

- **q** – numpy ndarray of N x M of M SRS functions with N samples
- **time** – vector of size N describing the sample points
- **mq** – median calculated using *time_warping.srsf_align()*
- **k** – cutoff threshold (default = 1.5)

Returns q_outlier: outlier functions

utility_functions.**randomGamma**(*gam*, *num*)
generates random warping functions

Parameters

- **gam** – numpy ndarray of N x M of M of warping functions
- **num** – number of random functions

Returns rgam: random warping functions

utility_functions.**resamplefunction**(*x*, *n*)
resample function using n points

Parameters

- **x** – functions
- **n** – number of points

Return type numpy array

Return xn resampled function

utility_functions.**rgam**(*N*, *sigma*, *num*)
Generates random warping functions

Parameters

- **N** – length of warping function
- **sigma** – variance of warping functions
- **num** – number of warping functions

Returns gam: numpy ndarray of warping functions utility_functions.**smooth_data**(*f*, *sparam*)

This function smooths a collection of functions using a box filter

Parameters

- **f** – numpy ndarray of shape (M,N) of M functions with N samples
- **sparam** – Number of times to run box filter (default = 25)

Return type numpy ndarray

Return f smoothed functions functions

utility_functions.**srsf_to_f**(*q*, *time*, *f0=0.0*)

converts q (srsf) to a function

Parameters

- **q** – vector of size N samples of srsf
- **time** – vector of size N describing time sample points
- **f0** – initial value

Return type vector

Return f function

utility_functions.**update_progress**(*progress*)

This function creates a progress bar

Parameters progress – fraction of progress

utility_functions.**warp_f_gamma**(*time*, *f*, *gam*)

warps a function f by gam

:param time vector describing time samples :param q vector describing srsf :param gam vector describing warping function

Return type numpy ndarray

Return f_temp warped srsf

utility_functions.**warp_q_gamma**(*time*, *q*, *gam*)

warps a srsf q by gam

:param time vector describing time samples :param q vector describing srsf :param gam vector describing warping function

Return type numpy ndarray

Return q_temp warped srsf

utility_functions.**zero_crossing**(*Y*, *q*, *bt*, *time*, *y_max*, *y_min*, *gmax*, *gmin*)

finds zero-crossing of optimal gamma, gam = s*gmax + (1-s)*gmin from elastic regression model

Parameters

- **Y** – response
- **q** – predicitve function
- **bt** – basis function
- **time** – time samples
- **y_max** – maximum repsonse for warping function gmax
- **y_min** – minimum response for warping function gmin

- **gmax** – max warping function
- **gmin** – min warping fucntion

Return type numpy array

Return gamma optimal warping function

CHAPTER

ELEVEN

CURVE FUNCTIONS

functions for SRVF curve manipulations

moduleauthor:: Derek Tucker <jdtuck@sandia.gov>

`curve_functions.`**`calc_j`**(*basis*)

Calculates Jacobian matrix from normal basis

Parameters **`basis`** – list of numpy ndarray of shape (2,M) of M samples basis

Return type numpy ndarray

Return j Jacobian

`curve_functions.`**`calculate_variance`**(*beta*)

This function calculates variance of curve beta

Parameters **`beta`** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return variance variance

`curve_functions.`**`calculatecentroid`**(*beta*)

This function calculates centroid of a parameterized curve

Parameters **`beta`** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return centroid center coordinates

`curve_functions.`**`curve_to_q`**(*beta*)

This function converts curve beta to srvf q

Parameters **`beta`** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return q srvf of curve

`curve_functions.`**`curve_zero_crossing`**(*Y*, *beta*, *bt*, *y_max*, *y_min*, *gmax*, *gmin*)

finds zero-crossing of optimal gamma, gam = s*gmax + (1-s)*gmin from elastic curve regression model

Parameters

- **`Y`** – response
- **`beta`** – predicitve function
- **`bt`** – basis function
- **`y_max`** – maximum repsonse for warping function gmax

- **y_min** – minimum response for warping function gmin
- **gmax** – max warping function
- **gmin** – min warping fucntion

Return type numpy array

Return gamma optimal warping function

Return O_hat rotation matrix

curve_functions.**find_basis_normal**(*q*)

Finds the basis normal to the srvf

Parameters q1 – numpy ndarray of shape (2,M) of M samples

Return type list of numpy ndarray

Return basis list containing basis vectors

curve_functions.**find_best_rotation**(*q1*, *q2*)

This function calculates the best rotation between two srvfs using procustes rigid alignment

Parameters

- **q1** – numpy ndarray of shape (2,M) of M samples
- **q2** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return q2new optimal rotated q2 to q1

Return R rotation matrix

curve_functions.**find_rotation_and_seed_coord**(*beta1*, *beta2*)

This function returns a candidate list of optimally oriented and registered (seed) shapes w.r.t. beta1

Parameters

- **beta1** – numpy ndarray of shape (2,M) of M samples
- **beta2** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return beta2new optimal rotated beta2 to beta1

Return O rotation matrix

Return tau seed

curve_functions.**find_rotation_and_seed_q**(*q1*, *q2*)

This function returns a candidate list of optimally oriented and registered (seed) shapes w.r.t. beta1

Parameters

- **q1** – numpy ndarray of shape (2,M) of M samples
- **q2** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return beta2new optimal rotated beta2 to beta1

Return O rotation matrix

Return tau seed

`curve_functions.`**`gram_schmidt`**(*basis*)

Performs Gram Schmidt Orthogonlization of a basis_o

param basis list of numpy ndarray of shape (2,M) of M samples

rtype list of numpy ndarray

return basis_o orthogonlized basis

`curve_functions.`**`group_action_by_gamma`**(*q*, *gamma*)

This function reparamerized srvf q by gamma

Parameters

- **`f`** – numpy ndarray of shape (2,M) of M samples
- **`gamma`** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return qn reparatermized srvf

`curve_functions.`**`group_action_by_gamma_coord`**(*f*, *gamma*)

This function reparamerized curve f by gamma

Parameters

- **`f`** – numpy ndarray of shape (2,M) of M samples
- **`gamma`** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return fn reparatermized curve

`curve_functions.`**`innerprod_q2`**(*q1*, *q2*)

This function calculates the inner product in srvf space

Parameters

- **`q1`** – numpy ndarray of shape (2,M) of M samples
- **`q2`** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return val inner product

`curve_functions.`**`inverse_exp`**(*q1*, *q2*, *beta2*)

Calculate the inverse exponential to obtain a shooting vector from q1 to q2 in shape space of open curves

Parameters

- **`q1`** – numpy ndarray of shape (2,M) of M samples
- **`q2`** – numpy ndarray of shape (2,M) of M samples
- **`beta2`** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return v shooting vectors

`curve_functions.`**`inverse_exp_coord`**(*beta1*, *beta2*)

Calculate the inverse exponential to obtain a shooting vector from beta1 to beta2 in shape space of open curves

Parameters

- **`beta1`** – numpy ndarray of shape (2,M) of M samples

- **beta2** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return v shooting vectors

Return dist distance

`curve_functions.`**`optimum_reparam_curve`**(*q1*, *q2*, *lam=0.0*)
calculates the warping to align srsf q2 to q1

Parameters

- **q1** – matrix of size nxN or array of NxM samples of first SRVF
- **time** – vector of size N describing the sample points
- **q2** – matrix of size nxN or array of NxM samples samples of second SRVF
- **lam** – controls the amount of elasticity (default = 0.0)

Return type vector

Return gam describing the warping function used to align q2 with q1

`curve_functions.`**`parallel_translate`**(*w*, *q1*, *q2*, *basis*, *mode=0*)
parallel translates q1 and q2 along manifold

Parameters

- **w** – numpy ndarray of shape (2,M) of M samples
- **q1** – numpy ndarray of shape (2,M) of M samples
- **q2** – numpy ndarray of shape (2,M) of M samples
- **basis** – list of numpy ndarray of shape (2,M) of M samples
- **mode** – open 0 or closed curves 1 (default 0)

Return type numpy ndarray

Return wbar translated vector

`curve_functions.`**`pre_proc_curve`**(*beta*, *T=100*)
This function prepcoessed a curve beta to set of closed curves

Parameters

- **beta** – numpy ndarray of shape (2,M) of M samples
- **T** – number of samples (default = 100)

Return type numpy ndarray

Return betanew projected beta

Return qnew projected srvf

Return A alignment matrix (not used currently)

`curve_functions.`**`project_curve`**(*q*)
This function projects srvf q to set of close curves

Parameters **q** – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return qproj project srvf

curve_functions.**project_tangent**(*w*, *q*, *basis*)
projects srvf to tangent space w using basis

Parameters

- **w** – numpy ndarray of shape (2,M) of M samples
- **q** – numpy ndarray of shape (2,M) of M samples
- **basis** – list of numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return wproj projected q

curve_functions.**psi**(*x*, *a*, *q*)
This function formats variance output

Parameters

- **x** – numpy ndarray of shape (2,M) of M samples curve
- **a** – numpy ndarray of shape (2,1) mean
- **q** – numpy ndarray of shape (2,M) of M samples srvf

Return type numpy ndarray

Return psi1 variance

Return psi2 cross variance

Return psi3 curve end

Return psi4 curve end

curve_functions.**q_to_curve**(*q*)
This function converts srvf to beta

Parameters q – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return beta parameterized curve

curve_functions.**resamplecurve**(*x*, *N=100*)
This function resamples a curve to have N samples

Parameters

- **x** – numpy ndarray of shape (2,M) of M samples
- **N** – Number of samples for new curve (default = 100)

Return type numpy ndarray

Return xn resampled curve

curve_functions.**scale_curve**(*beta*)
scales curve to length 1

Parameters beta – numpy ndarray of shape (2,M) of M samples

Return type numpy ndarray

Return beta_scaled scaled curve

Return scale scale factor used

`curve_functions.shift_f(f, tau)`

shifts a curve f by tau

Parameters

- **f** – numpy ndarray of shape (2,M) of M samples
- **tau** – scalar

Return type numpy ndarray

Return fn shifted curve

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