

# **LS-SVMlab Toolbox User's Guide**

## **version 1.7**

**K. De Brabanter, P. Karsmakers, F. Ojeda, C. Alzate,  
J. De Brabanter, K. Pelckmans, B. De Moor,  
J. Vandewalle, J.A.K. Suykens**

Katholieke Universiteit Leuven

Department of Electrical Engineering, ESAT-SCD-SISTA  
Kasteelpark Arenberg 10, B-3001 Leuven-Heverlee, Belgium  
{kris.debrabanter,johan.suykens}@esat.kuleuven.be

<http://www.esat.kuleuven.be/sista/lssvmlab/>

**ESAT-SISTA Technical Report 10-146**

September 2010



## Acknowledgements

Research supported by Research Council KUL: GOA AMBioRICS, GOA MaNet, CoE EF/05/006 Optimization in Engineering(OPTEC), IOF-SCORES4CHEM, several PhD/post-doc & fellow grants; Flemish Government: FWO: PhD/postdoc grants, projects G.0452.04 (new quantum algorithms), G.0499.04 (Statistics), G.0211.05 (Non-linear), G.0226.06 (cooperative systems and optimization), G.0321.06 (Tensors), G.0302.07 (SVM/Kernel), G.0320.08 (convex MPC), G.0558.08 (Robust MHE), G.0557.08 (Glycemia2), G.0588.09 (Brain-machine) research communities (ICCoS, ANMMM, MLDM); G.0377.09 (Mechatronics MPC), IWT: PhD Grants, McKnow-E, Eureka-Flite+, SBO LeCoPro, SBO Climaqs, POM, Belgian Federal Science Policy Office: IUAP P6/04 (DYSCO, Dynamical systems, control and optimization, 2007-2011); EU: ERNSI; FP7-HD-MPC (INFOS-ICT-223854), COST intelliCIS, EMBOCOM, Contract Research: AMINAL, Other: Helmholtz, viCERP, ACCM, Bauknecht, Hoerbiger. JS is a professor at K.U.Leuven Belgium. BDM and JWDW are full professors at K.U.Leuven Belgium.

# Preface to LS-SVMLab v1.7

We have added new functions to the toolbox and updated some of the existing commands with respect to the previous version v1.6. Because many readers are familiar with the layout of version 1.5 and version 1.6, we have tried to change it as little as possible. Here is a summary of the main changes:

- The major difference with the previous version is the optimization routine used to find the minimum of the cross-validation score function. The tuning procedure consists out of two steps: 1) Coupled Simulated Annealing determines suitable tuning parameters and 2) a simplex method uses these previous values as starting values in order to perform a fine-tuning of the parameters. The major advantage is speed. The number of function evaluations needed to find optimal parameters reduces from  $\pm 200$  in v1.6 to 50 in this version.
- The construction of bias-corrected approximate  $100(1 - \alpha)\%$  pointwise/simultaneous confidence and prediction intervals have been added to this version.
- Some bug-fixes are performed in the function `roc`. The class do not need to be  $+1$  or  $-1$ , but can also be 0 and 1. The conversion is automatically done.

*The LS-SVMLab Team  
Heverlee, Belgium  
September 2010*



# Preface to LS-SVMLab v1.6

We have added new functions to the toolbox and updated some of the existing commands with respect to the previous version v1.5. Because many readers are familiar with the layout of version 1.5, we have tried to change it as little as possible. The major difference is the speed-up of several methods. Here is a summary of the main changes:

Chapter/solver/function	What's new
1. A birds eye on LS-SVMLab	
2. LS-SVMLab toolbox examples	Roadmap to LS-SVM; Addition of more regression and classification examples; Easier interface for multi-class classification; Changed implementation for robust LS-SVM.
3. Matlab functions	Possibility of regression or classification using only one command!; The function <code>validate</code> has been deleted; Faster (robust) training and (robust) model selection criteria are provided; In case of robust regression different weight functions are provided to be used with iteratively reweighted LS-SVM.
4. LS-SVM solver	All CMEX and/or C files have been removed. The linear system is solved by using the Matlab command “backslash” ( <code>\</code> ).

*The LS-SVMLab Team  
Heverlee, Belgium  
June 2010*



# Contents

<b>1</b>	<b>Introduction</b>	<b>9</b>
<b>2</b>	<b>A birds eye view on LS-SVMlab</b>	<b>11</b>
2.1	Classification and regression . . . . .	11
2.1.1	Classification extensions . . . . .	12
2.1.2	Tuning and robustness . . . . .	12
2.1.3	Bayesian framework . . . . .	12
2.2	NARX models and prediction . . . . .	13
2.3	Unsupervised learning . . . . .	13
2.4	Solving large scale problems with fixed size LS-SVM . . . . .	13
<b>3</b>	<b>LS-SVMlab toolbox examples</b>	<b>15</b>
3.1	Roadmap to LS-SVM . . . . .	15
3.2	Classification . . . . .	15
3.2.1	Hello world . . . . .	15
3.2.2	Example . . . . .	17
3.2.3	Using the object oriented interface: <code>initlssvm</code> . . . . .	19
3.2.4	LS-SVM classification: only one command line away! . . . . .	19
3.2.5	Bayesian inference for classification . . . . .	20
3.2.6	Multi-class coding . . . . .	22
3.3	Regression . . . . .	23
3.3.1	A simple example . . . . .	23
3.3.2	LS-SVM regression: only one command line away! . . . . .	25
3.3.3	Bayesian Inference for Regression . . . . .	26
3.3.4	Using the object oriented model interface . . . . .	27
3.3.5	Confidence/Prediction Intervals for Regression . . . . .	28
3.3.6	Robust regression . . . . .	31
3.3.7	Multiple output regression . . . . .	33
3.3.8	A time-series example: Santa Fe laser data prediction . . . . .	34
3.3.9	Fixed size LS-SVM . . . . .	35
3.4	Unsupervised learning using kernel principal component analysis . . . . .	38
<b>A</b>	<b>MATLAB functions</b>	<b>39</b>
A.1	General notation . . . . .	39
A.2	Index of function calls . . . . .	40
A.2.1	Training and simulation . . . . .	40
A.2.2	Object oriented interface . . . . .	41
A.2.3	Training and simulating functions . . . . .	42
A.2.4	Kernel functions . . . . .	43
A.2.5	Tuning, sparseness and robustness . . . . .	44
A.2.6	Classification extensions . . . . .	45
A.2.7	Bayesian framework . . . . .	46

A.2.8	NARX models and prediction . . . . .	47
A.2.9	Unsupervised learning . . . . .	48
A.2.10	Fixed size LS-SVM . . . . .	49
A.2.11	Demos . . . . .	50
A.3	Alphabetical list of function calls . . . . .	51
A.3.1	AFEm . . . . .	51
A.3.2	bay_errorbar . . . . .	52
A.3.3	bay_initlssvm . . . . .	54
A.3.4	bay_lssvm . . . . .	55
A.3.5	bay_lssvmARD . . . . .	57
A.3.6	bay_modoutClass . . . . .	59
A.3.7	bay_optimize . . . . .	61
A.3.8	bay_rr . . . . .	63
A.3.9	cilssvm . . . . .	65
A.3.10	code, code_lssvm . . . . .	66
A.3.11	crossvalidate . . . . .	69
A.3.12	deltablssvm . . . . .	71
A.3.13	denoise_kpca . . . . .	72
A.3.14	eign . . . . .	73
A.3.15	gcrossvalidate . . . . .	74
A.3.16	initlssvm, changelssvm . . . . .	76
A.3.17	kentropy . . . . .	78
A.3.18	kernel_matrix . . . . .	79
A.3.19	kpca . . . . .	80
A.3.20	latentlssvm . . . . .	82
A.3.21	leaveoneout . . . . .	83
A.3.22	lin_kernel, MLP_kernel, poly_kernel, RBF_kernel . . . . .	85
A.3.23	linf, mae, medae, misclass, mse . . . . .	86
A.3.24	lssvm . . . . .	87
A.3.25	plotlssvm . . . . .	88
A.3.26	predict . . . . .	89
A.3.27	predlssvm . . . . .	91
A.3.28	preimage_rbf . . . . .	92
A.3.29	prelssvm, postlssvm . . . . .	93
A.3.30	rcrossvalidate . . . . .	94
A.3.31	ridgeregress . . . . .	96
A.3.32	robustlssvm . . . . .	97
A.3.33	roc . . . . .	98
A.3.34	simlssvm . . . . .	100
A.3.35	trainlssvm . . . . .	101
A.3.36	tunelssvm, linesearch & gridsearch . . . . .	103
A.3.37	windowize & windowizeNARX . . . . .	108



# Chapter 1

## Introduction

Support Vector Machines (SVM) is a powerful methodology for solving problems in nonlinear classification, function estimation and density estimation which has also led to many other recent developments in kernel based learning methods in general [14, 5, 27, 28, 48, 47]. SVMs have been introduced within the context of statistical learning theory and structural risk minimization. In the methods one solves convex optimization problems, typically quadratic programs. Least Squares Support Vector Machines (LS-SVM) are reformulations to standard SVMs [32, 43] which lead to solving linear KKT systems. LS-SVMs are closely related to regularization networks [10] and Gaussian processes [51] but additionally emphasize and exploit primal-dual interpretations. Links between kernel versions of classical pattern recognition algorithms such as kernel Fisher discriminant analysis and extensions to unsupervised learning, recurrent networks and control [33] are available. Robustness, sparseness and weightings [7, 34] can be imposed to LS-SVMs where needed and a Bayesian framework with three levels of inference has been developed [44]. LS-SVM alike primal-dual formulations are given to kernel PCA [37, 1], kernel CCA and kernel PLS [38]. For very large scale problems and on-line learning a method of Fixed Size LS-SVM is proposed [8], based on the Nyström approximation [12, 49] with active selection of support vectors and estimation in the primal space. The methods with primal-dual representations have also been developed for kernel spectral clustering [2], data visualization [39], dimensionality reduction and survival analysis [40]

The present *LS-SVMlab toolbox User's Guide* contains Matlab implementations for a number of LS-SVM algorithms related to classification, regression, time-series prediction and unsupervised learning. All functions are tested with Matlab R2008a, R2008b, R2009a, R2009b and R2010a. References to commands in the toolbox are written in **typewriter** font.

A main reference and overview on least squares support vector machines is

J.A.K. Suykens, T. Van Gestel, J. De Brabanter, B. De Moor, J. Vandewalle,  
*Least Squares Support Vector Machines*,  
World Scientific, Singapore, 2002 (ISBN 981-238-151-1).

The LS-SVMlab homepage is

<http://www.esat.kuleuven.be/sista/lssvmlab/>

The LS-SVMlab toolbox is made available under the GNU general license policy:

*Copyright (C) 2010 KULeuven-ESAT-SCD*

*This program is free software; you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation; either version 2 of the License, or (at your option) any later version.*

*This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the website of LS-SVMlab or the GNU General Public License for a copy of the GNU General Public License specifications.*

## Chapter 2

# A birds eye view on LS-SVMlab

The toolbox is mainly intended for use with the commercial Matlab package. The Matlab toolbox is compiled and tested for different computer architectures including Linux and Windows. Most functions can handle datasets up to 20.000 data points or more. LS-SVMlab's interface for Matlab consists of a basic version for beginners as well as a more advanced version with programs for multi-class encoding techniques and a Bayesian framework. Future versions will gradually incorporate new results and additional functionalities.

A number of functions are restricted to LS-SVMs (these include the extension “**lssvm**” in the function name), the others are generally usable. A number of demos illustrate how to use the different features of the toolbox. The Matlab function interfaces are organized in two principal ways: the functions can be called either in a *functional way* or using an *object oriented structure* (referred to as the **model**) as e.g. in Netlab [22], depending on the user's choice<sup>1</sup>.

## 2.1 Classification and regression

*Function calls:*      `trainlssvm, simlssvm, plotlssvm, prelssvm, postlssvm, cilssvm, predlssvm;`  
*Demos:* Subsections 3.2, 3.3, `demofun, democlass, democonfint.`

The Matlab toolbox is built around a fast LS-SVM training and simulation algorithm. The corresponding function calls can be used for classification as well as for function estimation. The function `plotlssvm` displays the simulation results of the **model** in the region of the training points.

The linear system is solved via the flexible and straightforward code implemented in Matlab (`lssvmMATLAB.m`), which is based on the Matlab matrix division (backslash command `\`).

Functions for single and multiple output regression and classification are available. Training and simulation can be done for each output separately by passing different kernel functions, kernel and/or regularization parameters as a column vector. It is straightforward to implement other kernel functions in the toolbox.

The performance of a model depends on the scaling of the input and output data. An appropriate algorithm detects and appropriately rescales continuous, categorical and binary variables (`prelssvm, postlssvm`).

An important tool accompanying the LS-SVM for function estimation is the construction of interval estimates such as confidence intervals. In the area of kernel based regression, a popular tool to construct interval estimates is the bootstrap (see e.g. [15] and reference therein). The functions `cilssvm` and `predlssvm` result in confidence and prediction intervals respectively for

---

<sup>1</sup>See <http://www.kernel-machines.org/software.html> for other software in kernel based learning techniques.

LS-SVM [9]. This method is not based on bootstrap and thus obtains in a fast way interval estimates.

### 2.1.1 Classification extensions

*Function calls:* `code1lssvm`, `code`, `deltablssvm`, `roc`, `latentlssvm`;  
*Demos:* Subsection 3.2, `democlass`.

A number of additional function files are available for the classification task. The latent variable of simulating a model for classification (`latentlssvm`) is the continuous result obtained by simulation which is discretised for making the final decisions. The Receiver Operating Characteristic curve [16] (`roc`) can be used to measure the performance of a classifier. Multiclass classification problems are decomposed into multiple binary classification tasks [45]. Several coding schemes can be used at this point: minimum output, one-versus-one, one-versus-all and error correcting coding schemes. To decode a given result, the Hamming distance, loss function distance and Bayesian decoding can be applied. A correction of the bias term can be done, which is especially interesting for small data sets.

### 2.1.2 Tuning and robustness

*Function calls:* `tunelssvm`, `crossvalidatelssvm`, `leaveoneoutlssvm`, `robustlssvm`;  
*Demos:* Subsections 3.2.2, 3.2.6, 3.3.6, 3.3.8, `demofun`, `democlass`, `demomodel`.

A number of methods to estimate the generalization performance of the trained model are included. For classification, the rate of misclassifications (`misclass`) can be used. Estimates based on repeated training and validation are given by `crossvalidatelssvm` and `leaveoneoutlssvm`. A robust crossvalidation (based on iteratively reweighted LS-SVM) score function [7, 6] is called by `rcrossvalidatelssvm`. In the case of outliers in the data, corrections to the support values will improve the model (`robustlssvm`) [34]. These performance measures can be used to determine the tuning parameters (e.g. the regularization and kernel parameters) of the LS-SVM (`tunelssvm`). In this version, the tuning of the parameters is conducted in two steps. First, a state-of-the-art global optimization technique, Coupled Simulated Annealing (CSA) [52], determines suitable parameters according to some criterion. Second, these parameters are then given to a second optimization procedure (`simplex` or `gridsearch`) to perform a fine-tuning step. CSA have already proven to be more effective than multi-start gradient descent optimization [35]. Another advantage of CSA is that it uses the acceptance temperature to control the variance of the acceptance probabilities with a control scheme. This leads to an improved optimization efficiency because it reduces the sensitivity of the algorithm to the initialization parameters while guiding the optimization process to quasi-optimal runs. By default, CSA uses five multiple starters.

### 2.1.3 Bayesian framework

*Function calls:* `bay_lssvm`, `bay_optimize`, `bay_lssvmARD`, `bay_errorbar`, `bay_modoutClass`, `kpca`, `eign`;  
*Demos:* Subsections 3.2.5, 3.3.3.

Functions for calculating the posterior probability of the model and hyper-parameters at different levels of inference are available (`bay_lssvm`) [41]. Errors bars are obtained by taking into account model- and hyper-parameter uncertainties (`bay_errorbar`). For classification [44], one can estimate the posterior class probabilities (this is also called the *moderated output*) (`bay_modoutClass`). The Bayesian framework makes use of the eigenvalue decomposition of the kernel matrix. The size of the matrix grows with the number of data points. Hence, one needs

approximation techniques to handle large datasets. It is known that mainly the principal eigenvalues and corresponding eigenvectors are relevant. Therefore, iterative approximation methods such as the Nyström method [46, 49] are included, which is also frequently used in Gaussian processes. Input selection can be done by Automatic Relevance Determination (`bay_1ssvmARD`) [42]. In a backward variable selection, the third level of inference of the Bayesian framework is used to infer the most relevant inputs of the problem.

## 2.2 NARX models and prediction

*Function calls:* `predict`, `windowize`;  
*Demo:* Subsection 3.3.8.

Extensions towards nonlinear NARX systems for time-series applications are available [38]. A NARX model can be built based on a nonlinear regressor by estimating in each iteration the next output value given the past output (and input) measurements. A dataset is converted into a new input (the past measurements) and output set (the future output) by `windowize` and `windowizeNARX` for respectively the time-series case and in general the NARX case with exogenous input. Iteratively predicting (in recurrent mode) the next output based on the previous predictions and starting values is done by `predict`.

## 2.3 Unsupervised learning

*Function calls:* `kpca`, `denoise_kpca`, `preimage_rbf`;  
*Demo:* Subsection 3.4.

Unsupervised learning can be done by kernel based PCA (`kpca`) as described by [30], for which a primal-dual interpretation with least squares support vector machine formulation has been given in [37], which has also been further extended to kernel canonical correlation analysis [38] and kernel PLS.

## 2.4 Solving large scale problems with fixed size LS-SVM

*Function calls:* `demo_fixedsize`, `AFEm`, `kentropy`;  
*Demos:* Subsection 3.3.9, `demo_fixedsize`, `demo_fixedclass`.

Classical kernel based algorithms like e.g. LS-SVM [32] typically have memory and computational requirements of  $O(N^2)$ . Work on large scale methods proposes solutions to circumvent this bottleneck [38, 30].

For large datasets it would be advantageous to solve the least squares problem in the primal weight space because then the size of the vector of unknowns is proportional to the feature vector dimension and not to the number of datapoints. However, the feature space mapping induced by the kernel is needed in order to obtain non-linearity. For this purpose, a method of fixed size LS-SVM is proposed [38]. Firstly the Nyström method [44, 49] can be used to estimate the feature space mapping. The link between Nyström approximation, kernel PCA and density estimation has been discussed in [12]. In fixed size LS-SVM these links are employed together with the explicit primal-dual LS-SVM interpretations. The support vectors are selected according to a quadratic Renyi entropy criterion (`kentropy`). In a last step a regression is done in the primal space which makes the method suitable for solving large scale nonlinear function estimation and classification problems. The method of fixed size LS-SVM is suitable for handling very large data sets.

An alternative criterion for subset selection was presented by [3, 4], which is closely related to [49] and [30]. It measures the quality of approximation of the feature space and the space induced

by the subset (see Automatic Feature Extraction or **AFEm**). In [49] the subset was taken as a random subsample from the data (**subsample**).

## Chapter 3

# LS-SVMlab toolbox examples

### 3.1 Roadmap to LS-SVM

In this Section we briefly sketch how to obtain an LS-SVM model (valid for classification and regression), see Figure 3.1.

1. Choose between the functional or objected oriented interface (`initlssvm`), see A.3.16
2. Search for suitable tuning parameters (`tunelssvm`), see A.3.36
3. Train the model given the previously determined tuning parameters (`trainlssvm`), see A.3.35
- 4a. Simulate the model on e.g. test data (`simlssvm`), see A.3.34
- 4b. Visualize the results when possible (`plotlssvm`), see A.3.25

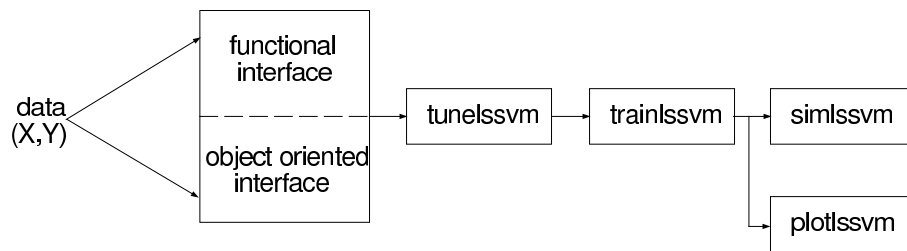


Figure 3.1: List of commands for obtaining an LS-SVM model

### 3.2 Classification

At first, the possibilities of the toolbox for classification tasks are illustrated.

#### 3.2.1 Hello world

A simple example shows how to start using the toolbox for a classification task. We start with constructing a simple example dataset according to the correct formatting. Data are represented as matrices where each row of the matrix contains one datapoint:

```
>> X = 2.*rand(100,2)-1;  
>> Y = sign(sin(X(:,1))+X(:,2));  
>> X
```

X =

```

    0.9003    -0.9695
   -0.5377     0.4936
    0.2137    -0.1098
   -0.0280     0.8636
    0.7826    -0.0680
    0.5242    -0.1627
    ....     ....
   -0.4556     0.7073
   -0.6024     0.1871

```

>> Y

Y =

```

   -1
   -1
    1
    1
    1
    1
    ...
    1
   -1

```

In order to make an LS-SVM model (with Gaussian RBF kernel), we need two tuning parameters:  $\gamma$  (**gam**) is the regularization parameter, determining the trade-off between the training error minimization and smoothness. In the common case of the Gaussian RBF kernel,  $\sigma^2$  (**sig2**) is the squared bandwidth:

```

>> gam = 10;
>> sig2 = 0.4;
>> type = 'classification';
>> [alpha,b] = trainlssvm({X,Y,type,gam,sig2,'RBF_kernel'});

```

The parameters and the variables relevant for the LS-SVM are passed as one cell. This cell allows for consistent default handling of LS-SVM parameters and syntactical grouping of related arguments. This definition should be used consistently throughout the use of that LS-SVM model. The corresponding object oriented interface to LS-SVMlab leads to shorter function calls (see **demomodel**).

By default, the data are **preprocessed** by application of the function **prelssvm** to the raw data and the function **postlssvm** on the predictions of the model. This option can explicitly be switched off in the call:

```

>> [alpha,b] = trainlssvm({X,Y,type,gam,sig2,'RBF_kernel','original'});

```

or be switched on (by default):

```

>> [alpha,b] = trainlssvm({X,Y,type,gam,sig2,'RBF_kernel','preprocess'});

```

Remember to consistently use the same option in all successive calls.

To evaluate new points for this model, the function **simlssvm** is used.

```

>> Xt = 2.*rand(10,2)-1;
>> Ytest = simlssvm({X,Y,type,gam,sig2,'RBF_kernel'},{alpha,b},Xt);

```



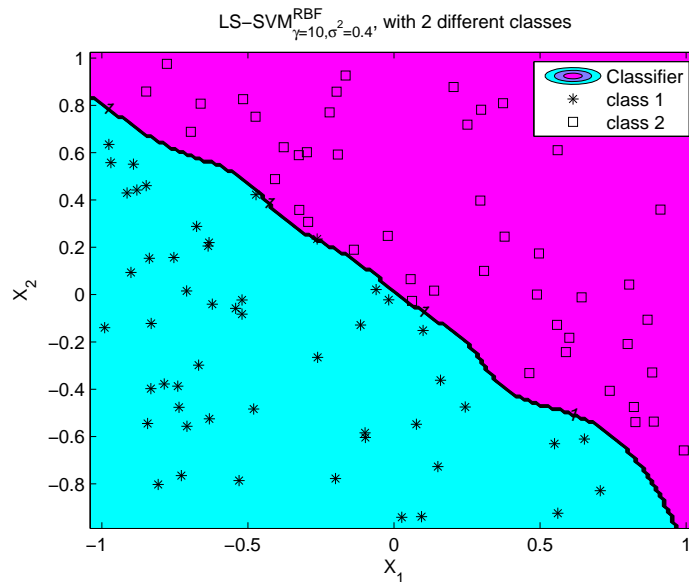


Figure 3.2: Figure generated by `plotlssvm` in the simple classification task.

The LS-SVM result can be displayed if the dimension of the input data is two.

```
>> plotlssvm({X,Y,type,gam,sig2,'RBF_kernel'},{alpha,b});
```

All plotting is done with this simple command. It looks for the best way of displaying the result (Figure 3.2).

### 3.2.2 Example

The well-known Ripley dataset problem consists of two classes where the data for each class have been generated by a mixture of two normal distributions (Figure 3.3a).

First, let us build an LS-SVM on the dataset and determine suitable tuning parameters. These tuning parameters are found by using a combination of Coupled Simulated Annealing (CSA) and a standard simplex method. First, CSA finds good starting values and these are passed to the simplex method in order to fine tune the result.

```
>> % load dataset ...
>> type = 'classification';
>> L_fold = 10; % L-fold crossvalidation
>> [gam,sig2] = tunelssvm({X,Y,type,[],[],'RBF_kernel'},'simplex',...
    'crossvalidatelssvm',{L_fold,'misclass'});
>> [alpha,b] = trainlssvm({X,Y,type,gam,sig2,'RBF_kernel'});
>> plotlssvm({X,Y,type,gam,sig2,'RBF_kernel'},{alpha,b});
```

It is still possible to use a gridsearch in the second run i.e. as a replacement for the simplex method

```
>> [gam,sig2] = tunelssvm({X,Y,type,[],[],'RBF_kernel'},'gridsearch',...
    'crossvalidatelssvm',{L_fold,'misclass'});
```

The Receiver Operating Characteristic (ROC) curve gives information about the quality of the classifier:

```
>> [alpha,b] = trainlssvm({X,Y,type,gam,sig2,'RBF_kernel'});
```

```

>> % latent variables are needed to make the ROC curve
>> Y_latent = latentlssvm({X,Y,type,gam,sig2,'RBF_kernel'},{alpha,b},X);
>> [area,se,thresholds,oneMinusSpec,Sens]=roc(Y_latent,Y);
>> [thresholds oneMinusSpec Sens]
ans =
    -2.1915    1.0000    1.0000
    -1.1915    0.9920    1.0000
    -1.1268    0.9840    1.0000
    -1.0823    0.9760    1.0000

    ...      ...      ...

   -0.2699    0.1840    0.9360
   -0.2554    0.1760    0.9360

   -0.2277    0.1760    0.9280
   -0.1811    0.1680    0.9280

    ...      ...      ...

    1.1184         0    0.0080
    1.1220         0         0
    2.1220         0         0

```

The corresponding ROC curve is shown on Figure 3.3b.

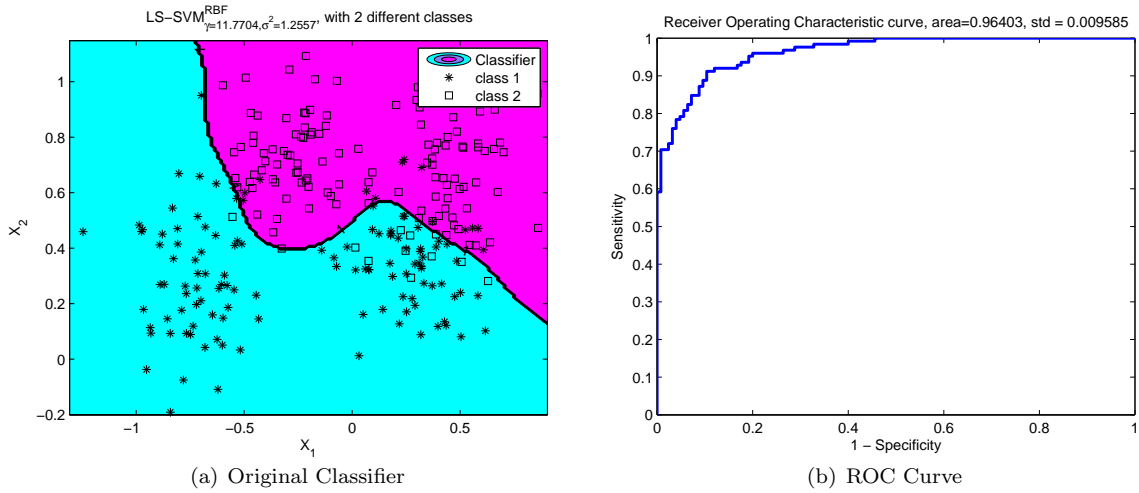


Figure 3.3: ROC curve of the Ripley classification task. (a) Original LS-SVM classifier. (b) Receiver Operating Characteristic curve.

### 3.2.3 Using the object oriented interface: `initlssvm`

Another possibility to obtain the same results is by using the object oriented interface. This goes as follows:

```
>> % load dataset ...
>> % gateway to the object oriented interface
>> model = initlssvm(X,Y,type,[],[],'RBF_kernel');

>> model = tunelssvm(model,'simplex','crossvalidatelssvm',{L_fold,'misclass'});
>> model = trainlssvm(model);
>> plotlssvm(model);

>> % latent variables are needed to make the ROC curve
>> Y_latent = latentlssvm(model,X);
>> [area,se,thresholds,oneMinusSpec,Sens]=roc(Y_latent,Y);
```

### 3.2.4 LS-SVM classification: only one command line away!

The simplest way to obtain an LS-SVM model goes as follows (binary classification problems and one versus one encoding for multiclass)

```
>> % load dataset ...
>> type = 'classification';
>> Yp = lssvm(X,Y,type);
```

The `lssvm` command automatically tunes the tuning parameters via 10-fold cross-validation (CV) or leave-one-out CV depending on the sample size. This function will automatically plot (when possible) the solution. By default, the Gaussian RBF kernel is taken. Further information can be found in A.3.24.

### 3.2.5 Bayesian inference for classification

This Subsection further proceeds on the results of Subsection 3.2.2. A Bayesian framework is used to optimize the tuning parameters and to obtain the moderated output. The optimal regularization parameter `gam` and kernel parameter `sig2` can be found by optimizing the cost on the second and the third level of inference, respectively. It is recommended to initiate the model with appropriate starting values:

```
>> [gam, sig2] = bay_initlssvm({X,Y,type,gam,sig2,'RBF_kernel'});
```

Optimization on the second level leads to an optimal regularization parameter:

```
>> [model, gam_opt] = bay_optimize({X,Y,type,gam,sig2,'RBF_kernel'},2);
```

Optimization on the third level leads to an optimal kernel parameter:

```
>> [cost_L3,sig2_opt] = bay_optimize({X,Y,type,gam_opt,sig2,'RBF_kernel'},3);
```

The posterior class probabilities are found by incorporating the uncertainty of the model parameters:

```
>> gam = 10;
>> sig2 = 1;
>> Ymodout = bay_modoutClass({X,Y,type,10,1,'RBF_kernel'},'figure');
```

One can specify a prior class probability in the moderated output in order to compensate for an unbalanced number of training data points in the two classes. When the training set contains  $N^+$  positive instances and  $N^-$  negative ones, the moderated output is calculated as:

$$\text{prior} = \frac{N^+}{N^+ + N^-}$$

```
>> Np = 10;
>> Nn = 50;
>> prior = Np / (Nn + Np);
>> Posterior_class_P = bay_modoutClass({X,Y,type,10,1,'RBF_kernel'},...
                                     'figure', prior);
```

The results are shown in Figure 3.4.

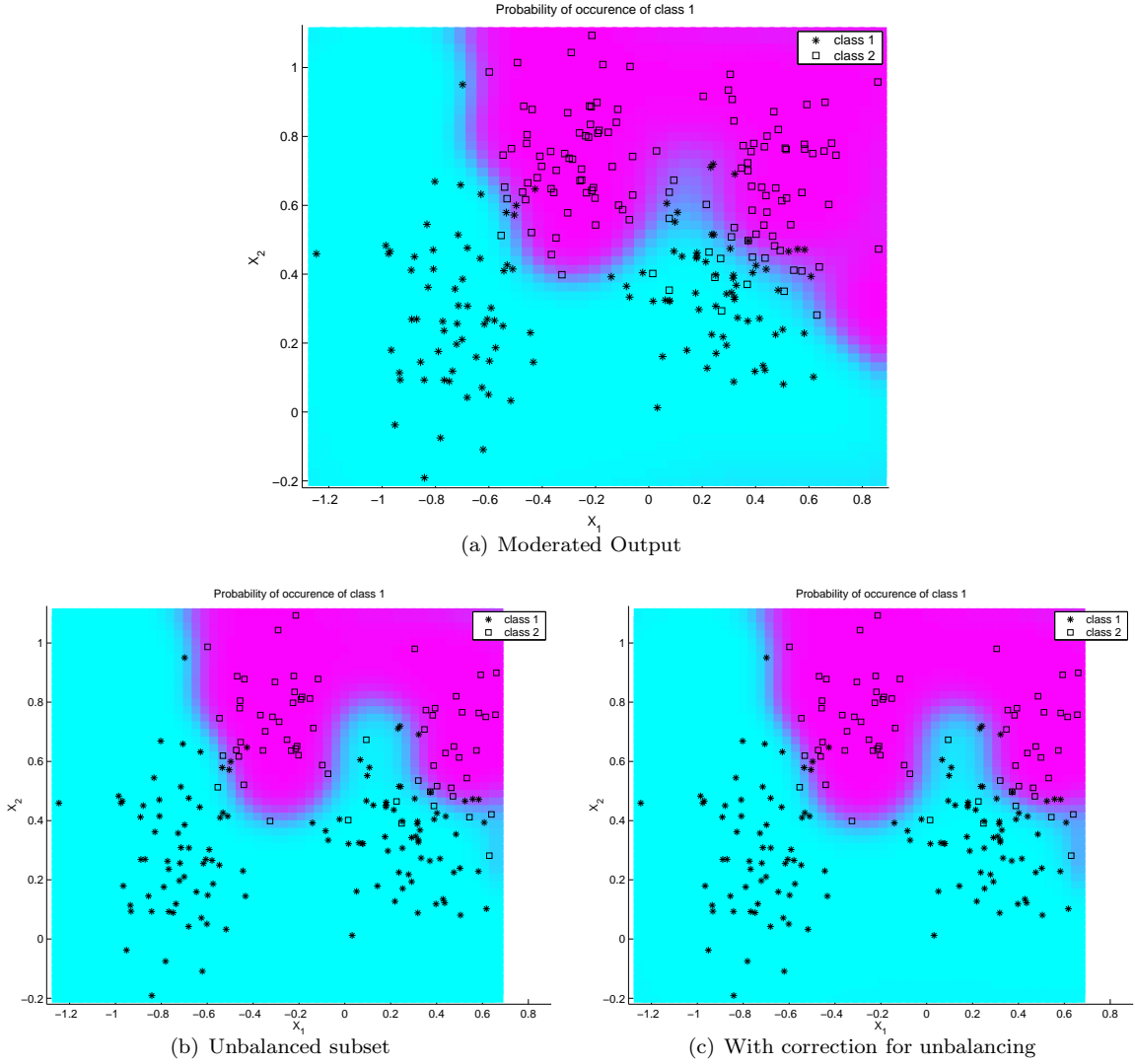


Figure 3.4: (a) Moderated output of the LS-SVM classifier on the Ripley data set. The colors indicate the probability to belong to a certain class; (b) This example shows the moderated output of an unbalanced subset of the Ripley data; (c) One can compensate for unbalanced data in the calculation of the moderated output. Notice that the area of the blue zone with the positive samples increases by the compensation. The red zone shrinks accordingly.

### 3.2.6 Multi-class coding

The following example shows how to use an encoding scheme for multi-class problems. The encoding and decoding are considered as a separate and independent preprocessing and postprocessing step respectively (Figure 3.5(a) and 3.5(b)). A demo file `demomulticlass` is included in the toolbox.

```
>> % load multiclass data ...
>> [Ycode, codebook, old_codebook] = code(Y,'code_MOC');
>>
>> [alpha,b] = trainlssvm({X,Ycode,'classifier',gam,sig2});
>> Yhc = simlssvm({X,Ycode,'classifier',gam,sig2},{alpha,b},Xtest);
>>
>> Yhc = code(Yh,old_codebook,[],codebook,'codedist_hamming');
```

In multiclass classification problems, it is easiest to use the object oriented interface which integrates the encoding in the LS-SVM training and simulation calls:

```
>> % load multiclass data ...
>> model = initlssvm(X,Y,'classifier',[],[],'RBF_kernel');
>> model = tunelssvm(model,'simplex',...
                    'leaveoneoutlssvm',{'misclass'},'code_OneVsOne');
>> model = trainlssvm(model);
>> plotlssvm(model);
```

The last argument of the `tunelssvm` routine can be set to

- `code_OneVsOne`: One versus one coding
- `code_MOC`: Minimum output coding
- `code_ECOC`: Error correcting output code
- `code_OneVsAll`: One versus all coding

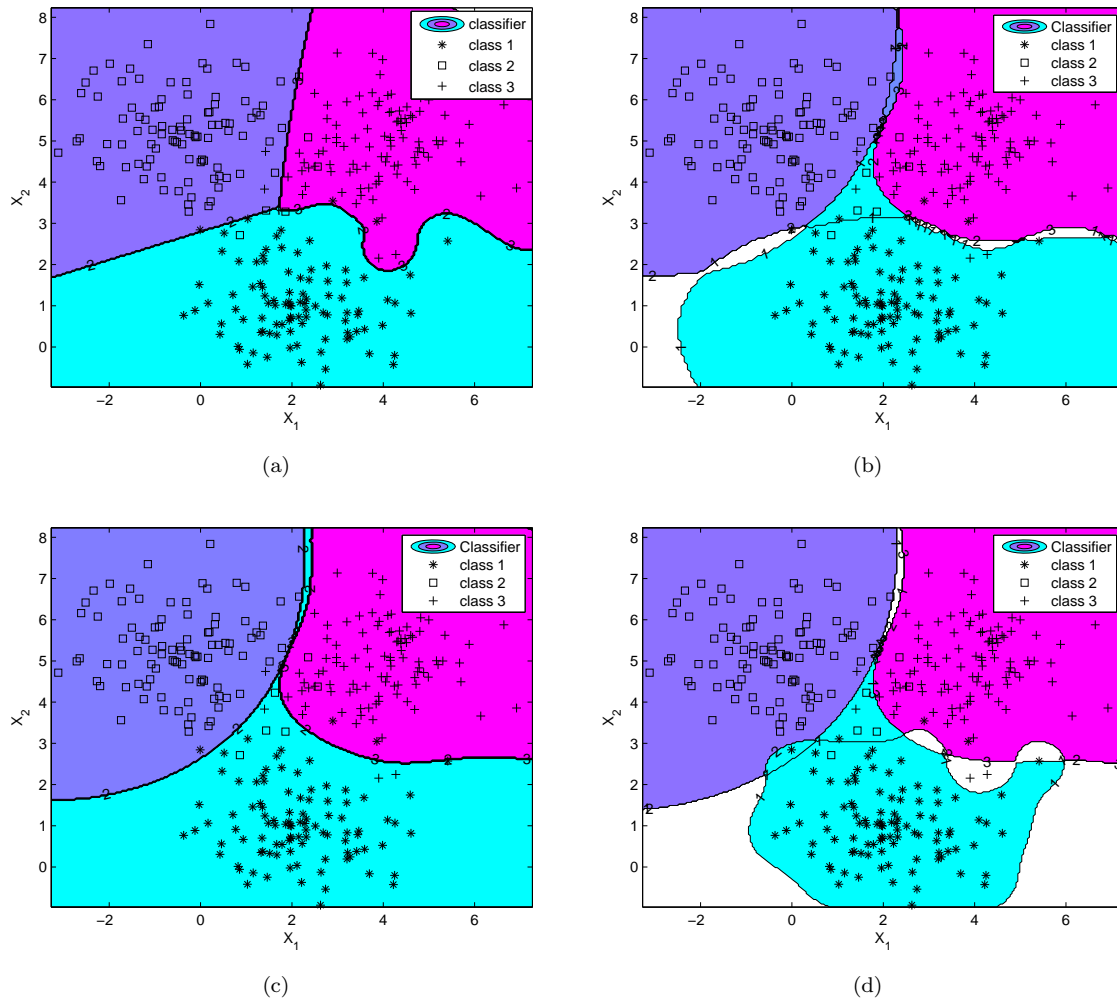


Figure 3.5: LS-SVM multi-class example: (a) one versus one encoding; (b) error correcting output code; (c) Minimum output code; (d) One versus all encoding.

### 3.3 Regression

#### 3.3.1 A simple example

This is a simple demo, solving a simple regression task using LS-SVMlab. A dataset is constructed in the correct formatting. The data are represented as matrices where each row contains one datapoint:

```
>> X = linspace(-1,1,50)';
>> Y = (15*(X.^2-1).^2.*X.^4).*exp(-X)+normrnd(0,0.1,length(X),1);
>> X
```

X =

```
-1.0000
-0.9592
-0.9184
-0.8776
```

```

-0.8367
-0.7959
...
0.9592
1.0000

>> Y =

Y =

    0.0138
    0.2953
    0.6847
    1.1572
    1.5844
    1.9935
    ...
   -0.0613
   -0.0298

```

In order to obtain an LS-SVM model (with the RBF kernel), we need two extra tuning parameters:  $\gamma$  (**gam**) is the regularization parameter, determining the trade-off between the training error minimization and smoothness of the estimated function.  $\sigma^2$  (**sig2**) is the kernel function parameter. In this case we use leave-one-out CV to determine the tuning parameters.

```

>> type = 'function estimation';
>> [gam,sig2] = tunelssvm({X,Y,type,[],[],'RBF_kernel'},'simplex',...
                        'leaveoneoutlssvm',{'mse'});
>> [alpha,b] = trainlssvm({X,Y,type,gam,sig2,'RBF_kernel'});
>> plotlssvm({X,Y,type,gam,sig2,'RBF_kernel'},{alpha,b});

```

The parameters and the variables relevant for the LS-SVM are passed as one cell. This cell allows for consistent default handling of LS-SVM parameters and syntactical grouping of related arguments. This definition should be used consistently throughout the use of that LS-SVM model. The object oriented interface to LS-SVMLab leads to shorter function calls (see **demomodel**).

By default, the data are **preprocessed** by application of the function **prelssvm** to the raw data and the function **postlssvm** on the predictions of the model. This option can be explicitly switched off in the call:

```

>> [alpha,b] = trainlssvm({X,Y,type,gam,sig2,'RBF_kernel','original'});

```

or can be switched on (by default):

```

>> [alpha,b] = trainlssvm({X,Y,type,gam,sig2,'RBF_kernel','preprocess'});

```

Remember to consistently use the same option in all successive calls.

To evaluate new points for this model, the function **simlssvm** is used. At first, test data is generated:

```

>> Xt = rand(10,1).*sign(randn(10,1));

```

Then, the obtained model is simulated on the test data:



```
>> Yt = simlssvm({X,Y,type,gam,sig2,'RBF_kernel','preprocess'},{alpha,b},Xt);

ans =

    0.0847
    0.0378
    1.9862
    0.4688
    0.3773
    1.9832
    0.2658
    0.2515
    1.5571
    0.3130
```

The LS-SVM result can be displayed if the dimension of the input data is one or two.

```
>> plotlssvm({X,Y,type,gam,sig2,'RBF_kernel','preprocess'},{alpha,b});
```

All plotting is done with this simple command. It looks for the best way of displaying the result (Figure 3.6).

### 3.3.2 LS-SVM regression: only one command line away!

As an alternative one can use the one line `lssvm` command:

```
>> type = 'function estimation';
>> Yp = lssvm(X,Y,type);
```

By default, the Gaussian RBF kernel is used. Further information can be found in A.3.24.

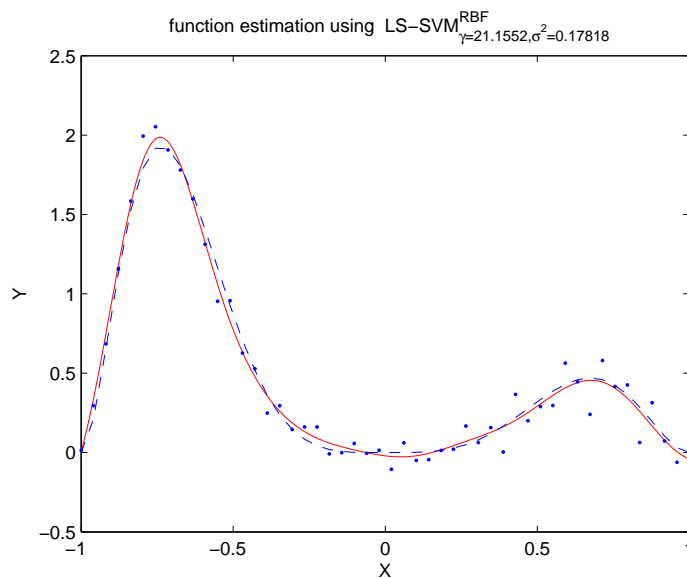


Figure 3.6: Simple regression problem. The solid line indicates the estimated outputs, the dotted line represents the true underlying function. The dots indicate the training data points.

### 3.3.3 Bayesian Inference for Regression

An example on the sinc data is given:

```
>> type = 'function approximation';
>> X = linspace(-2.2,2.2,250)';
>> Y = sinc(X) + normrnd(0,.1,size(X,1),1);
>> [Yp,alpha,b,gam,sig2] = lssvm(X,Y,type);
```

The errorbars on the training data are computed using Bayesian inference:

```
>> sig2e = bay_errorbar({X,Y,type, gam, sig2},'figure');
```

See Figure 3.7 for the resulting error bars.

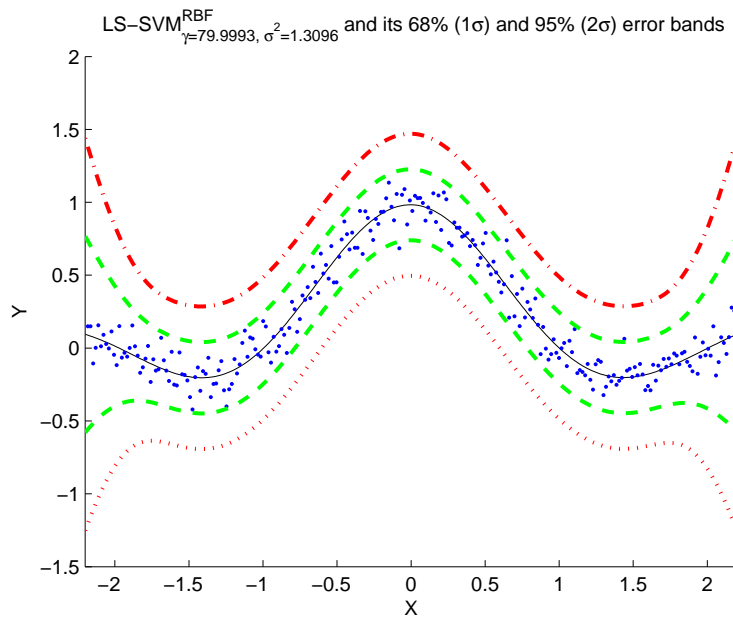


Figure 3.7: This figure gives the 68% errorbars (green dotted and green dashed-dotted line) and the 95% error bars (red dotted and red dashed-dotted line) of the LS-SVM estimate (solid line) of a simple sinc function.

In the next example, the procedure of the automatic relevance determination is illustrated:

```
>> X = normrnd(0,2,100,3);
>> Y = sinc(X(:,1)) + 0.05.*X(:,2) + normrnd(0,.1,size(X,1),1);
```

Automatic relevance determination is used to determine the subset of the most relevant inputs for the proposed model:

```
>> inputs = bay_lssvmARD({X,Y,type, 10,3});
>> [alpha,b] = trainlssvm({X(:,inputs),Y,type, 10,1});
```

### 3.3.4 Using the object oriented model interface

This case illustrates how one can use the model interface. Here, regression is considered, but the extension towards classification is analogous.

```
>> type = 'function approximation';
>> X = normrnd(0,2,100,1);
>> Y = sinc(X) + normrnd(0,.1,size(X,1),1);
>> kernel = 'RBF_kernel';
>> gam = 10;
>> sig2 = 0.2;
```

A model is defined

```
>> model = initlssvm(X,Y,type,gam,sig2,kernel);
>> model
```

model =

```

        type: 'f'
      x_dim: 1
      y_dim: 1
    nb_data: 100
  kernel_type: 'RBF_kernel'
  preprocess: 'preprocess'
  prestatus: 'ok'
    xtrain: [100x1 double]
    ytrain: [100x1 double]
    selector: [1x100 double]
      gam: 10
  kernel_pars: 0.2000
    x_delays: 0
    y_delays: 0
    steps: 1
    latent: 'no'
      code: 'original'
    codetype: 'none'
  pre_xscheme: 'c'
  pre_yscheme: 'c'
    pre_xmean: -0.0690
    pre_xstd: 1.8282
    pre_ymean: 0.2259
    pre_ystd: 0.3977
    status: 'changed'
    weights: []

```

Training, simulation and making a plot is executed by the following calls:

```
>> model = trainlssvm(model);
>> Xt = normrnd(0,2,150,1);
>> Yt = simlssvm(model,Xt);
>> plotlssvm(model);
```

The second level of inference of the Bayesian framework can be used to optimize the regularization parameter `gam`. For this case, a Nyström approximation of the 20 principal eigenvectors is used:

```
>> model = bay_optimize(model,2,'eign', 50);
```

Optimization of the cost associated with the third level of inference gives an optimal kernel parameter. For this procedure, it is recommended to initiate the starting points of the kernel parameter. This optimization is based on Matlab's optimization toolbox. It can take a while.

```
>> model = bay_initlssvm(model);
>> model = bay_optimize(model,3,'eign',50);
```

### 3.3.5 Confidence/Prediction Intervals for Regression

Consider the following example: Fossil data set

```
>> % Load data set X and Y
```

Initializing and tuning the parameters

```
>> model = initlssvm(X,Y,'f',[[],[]], 'RBF_kernel','o');
>> model = tunelssvm(model,'simplex','crossvalidate_lssvm',{10,'mse'});
```

Bias corrected approximate  $100(1 - \alpha)\%$  pointwise confidence intervals on the estimated LS-SVM model can then be obtained by using the command `cilssvm`:

```
>> ci = cilssvm(model,alpha,'pointwise');
```

Typically, the value of the significance level `alpha` is set to 5%. The confidence intervals obtained by this command are pointwise. For example, by looking at two pointwise confidence intervals in Figure 3.8(a) (Fossil data set [26]) we can make the following two statements *separately*

- (0.70743,0.70745) is an approximate 95% pointwise confidence interval for  $m(105)$ ;
- (0.70741,0.70744) is an approximate 95% pointwise confidence interval for  $m(120)$ .

However, as is well known in multiple comparison theory, it is wrong to state that  $m(105)$  is contained in (0.70743,0.70745) and *simultaneously*  $m(120)$  is contained in (0.70741,0.70744) with 95% confidence. Therefore, it is not correct to connect the pointwise confidence intervals to produce a band around the estimated function. In order to make these statements we have to modify the interval to obtain simultaneous confidence intervals. Three major groups exist to modify the interval: Monte Carlo simulations, Bonferroni, Šidák corrections and results based on distributions of maxima and upcrossing theory [25, 36, 18]. The latter is implemented in the software. Figure 3.8(b) shows the 95% pointwise and simultaneous confidence intervals on the estimated LS-SVM model. As expected the simultaneous intervals are much wider than pointwise intervals. Simultaneous confidence intervals can be obtained by

```
>> ci = cilssvm(model,alpha,'simultaneous');
```

In some cases one may also be interested in the uncertainty on the prediction for a new observation  $X_t$ . This type of requirement is fulfilled by the construction of a prediction interval. As before, pointwise and simultaneous prediction intervals can be found by

```
>> pi = predlssvm(model,Xt,alpha,'pointwise');
```

and

```
>> pi = predlssvm(model,Xt,alpha,'simultaneous');
```

respectively. We illustrate both type of prediction intervals on the following example. Note that the software can also handle heteroscedastic data. Also, the `cilssvm` and `predlssvm` can be called by the functional interface (see A.3.9 and A.3.27).

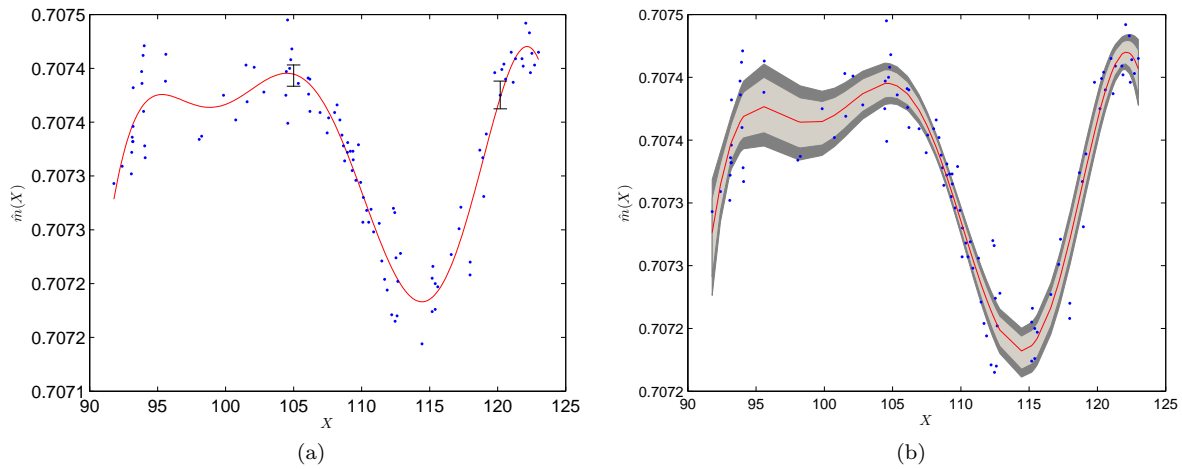


Figure 3.8: **(a)** Fossil data with two pointwise 95% confidence intervals.; **(b)** Simultaneous and pointwise 95% confidence intervals. The outer (inner) region corresponds to simultaneous (point-wise) confidence intervals. The full line (in the middle) is the estimated LS-SVM model. For illustration purposes the 95% pointwise confidence intervals are connected.

```
>> X = linspace(-5,5,200)';
>> Y = sin(X)+sqrt(0.05*X.^2+0.01).*randn(200,1);
>> model = initlssvm(X,Y,'f',[[],[]], 'RBF_kernel','o');
>> model = tunelssvm(model,'simplex','crossvalidate1ssvm',{10,'mae'});

>> Xt = linspace(-4.5,4.7,200)';
```

Figure 3.9 shows the 95% pointwise and simultaneous prediction intervals on the test set  $X_t$ . As expected the simultaneous intervals are again much wider than pointwise intervals.

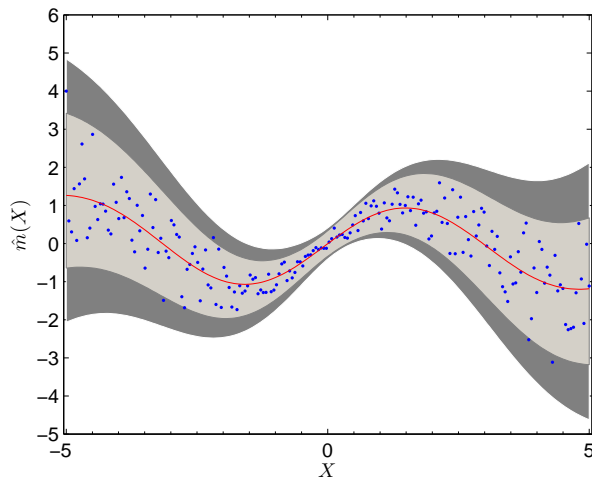


Figure 3.9: Pointwise and simultaneous 95% prediction intervals for the above given data. The outer (inner) region corresponds to simultaneous (pointwise) prediction intervals. The full line (in the middle) is the estimated LS-SVM model. For illustration purposes the 95% pointwise prediction intervals are connected.

As a final example, consider the Boston Housing data set (multivariate example). We selected randomly 338 training data points and 168 test data points. The corresponding simultaneous confidence and prediction intervals are shown in Figure 3.10(a) and Figure 3.10(b) respectively. The outputs on training as well as on test data are sorted and plotted against their corresponding index. Also, the respective intervals are sorted accordingly. For illustration purposes the simultaneous confidence/prediction intervals are not connected.

```
>> % load full data set X and Y
>> sel = randperm(506);
>>
>> % Construct test data
>> Xt = X(sel(1:168),:);
>> Yt = Y(sel(1:168));
>>
>> % training data
>> X = X(sel(169:end),:);
>> Y = Y(sel(169:end));
>>
>> model = initlssvm(X,Y,'f',[[],[]],'RBF_kernel','o');
>> model = tunelssvm(model,'simplex','crossvalidate1ssvm',{10,'mse'});
>> model = trainlssvm(model);
>> Yhci = simlssvm(model,X);
>> Yhpi = simlssvm(model,Xt);
>> [Yhci,indci] = sort(Yhci,'descend');
>> [Yhpi,indpi] = sort(Yhpi,'descend');
>>
>> % Simultaneous confidence intervals
>> ci = cilssvm(model,0.05,'simultaneous'); ci = ci(indci,:);
>> plot(Yhci); hold all, plot(ci(:,1),'g. '); plot(ci(:,2),'g. ');
>>
>> % Simultaneous prediction intervals
>> pi = predlssvm(model,Xt,0.05,'simultaneous'); pi = pi(indpi,:);
>> plot(Yhpi); hold all, plot(pi(:,1),'g. '); plot(pi(:,2),'g. ');
```

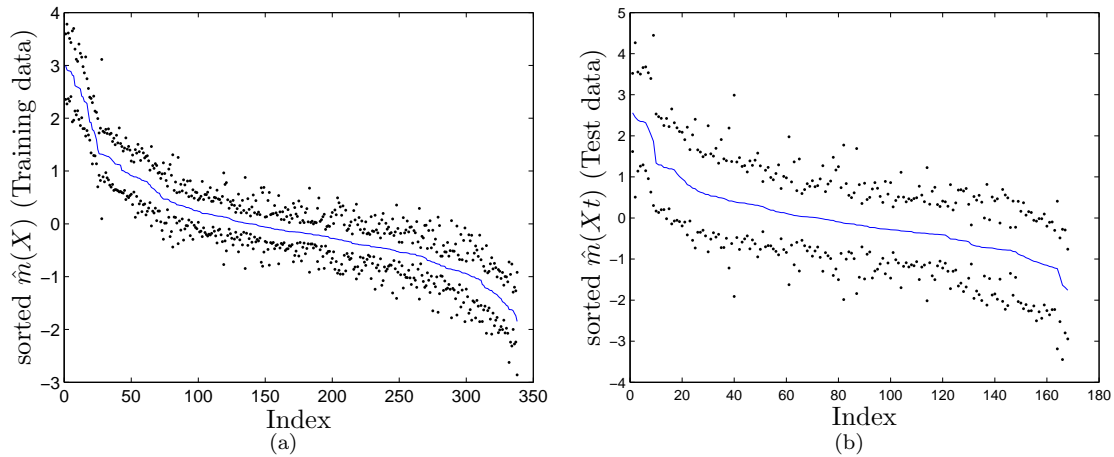


Figure 3.10: (a) Simultaneous 95% confidence intervals for the Boston Housing data set (dots). Sorted outputs are plotted against their index; (b) Simultaneous 95% prediction intervals for the Boston Housing data set (dots). Sorted outputs are plotted against their index.

### 3.3.6 Robust regression

First, a dataset containing 15% outliers is constructed:

```
>> X = (-5:.07:5)';
>> epsilon = 0.15;
>> sel = rand(length(X),1)>epsilon;
>> Y = sinc(X)+sel.*normrnd(0,.1,length(X),1)+(1-sel).*normrnd(0,2,length(X),1);
```

Robust tuning of the tuning parameters is performed by `rcrossvalldatelssvm`. Also notice that the preferred loss function is the  $L_1$  (mae). The weighting function in the cost function is chosen to be the Huber weights. Other possibilities, included in the toolbox, are logistic weights, myriad weights and Hampel weights.

```
>> model = initlssvm(X,Y,'f',[[],[]],'RBF_kernel');
>> L_fold = 10; %10 fold CV
>> model = tunelssvm(model,'simplex',...
    'rcrossvalldatelssvm',{L_fold,'mae'},'whuber');
```

Robust training is performed by `robustlssvm`:

```
>> model = robustlssvm(model);
>> plotlssvm(model);
```

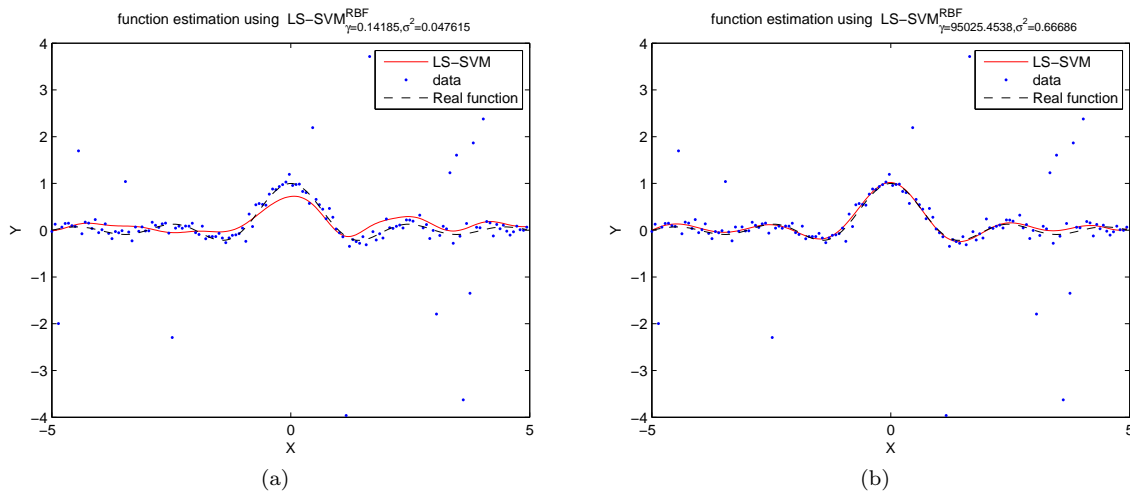


Figure 3.11: Experiments on a noisy sinc dataset with 15% outliers: (a) Application of the standard training and hyperparameter selection techniques; (b) Application of an iteratively reweighted LS-SVM training together with a robust crossvalidation score function, which enhances the test set performance.

In a second, more extreme, example, we have taken the contamination distribution to be a cubic standard Cauchy distribution and  $\epsilon = 0.3$ .

```
>> X = (-5:.07:5)';
>> epsilon = 0.3;
>> sel = rand(length(X),1)>epsilon;
>> Y = sinc(X)+sel.*normrnd(0,.1,length(X),1)+(1-sel).*trnd(1,length(X),1).^3;
```

As before, we use the robust version of cross-validation. The weight function in the cost function is chosen to be the myriad weights. All weight functions  $W : \mathbb{R} \rightarrow [0, 1]$ , with  $W(r) = \frac{\psi(r)}{r}$  satisfying  $W(0) = 1$ , are shown in Table 3.1 with corresponding loss function  $L(r)$  and score function  $\psi(r) = \frac{dL(r)}{dr}$ . This type of weighting function is especially designed to handle extreme outliers. The results are shown in Figure 3.12. Three of the four weight functions contain parameters which have to be tuned (see Table 3.1). The software automatically tunes the parameters of the huber and myriad weight function according to the best performance for these two weight functions. The two parameters of the Hampel weight function are set to  $b_1 = 2.5$  and  $b_2 = 3$ .

```
>> model = initlssvm(X,Y,'f',[[],[]],'RBF_kernel');
>> L_fold = 10; %10 fold CV
>> model = tunelssvm(model,'simplex',...
                    'rcrossvalidatelssvm',{L_fold,'mae'},'wmyriad');
>> model = robustlssvm(model);
>> plotlssvm(model);
```

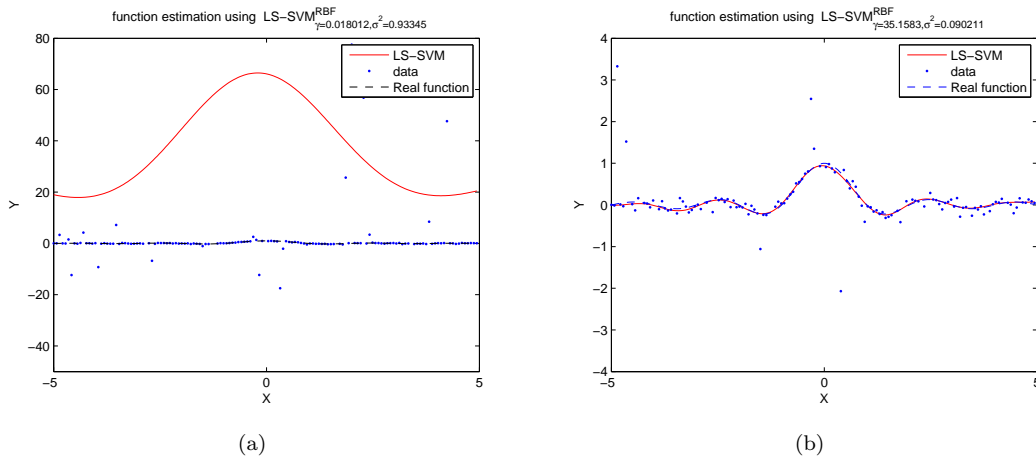
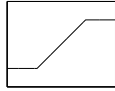
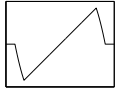
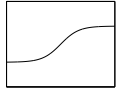
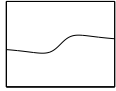


Figure 3.12: Experiments on a noisy sinc dataset with extreme outliers. **(a)** Application of the standard training and tuning parameter selection techniques; **(b)** Application of an iteratively reweighted LS-SVM training (myriad weights) together with a robust cross-validation score function, which enhances the test set performance;



Table 3.1: Definitions for the Huber, Hampel, Logistic and Myriad (with parameter  $\delta \in \mathbb{R}_0^+$ ) weight functions  $W(\cdot)$ . The corresponding loss  $L(\cdot)$  and score function  $\psi(\cdot)$  are also given.

	Huber	Hampel	Logistic	Myriad
$W(r)$	$\begin{cases} 1, & \text{if }  r  < \beta; \\ \frac{\beta}{ r }, & \text{if }  r  \geq \beta. \end{cases}$	$\begin{cases} 1, & \text{if }  r  < b_1; \\ \frac{b_2 -  r }{b_2 - b_1}, & \text{if } b_1 \leq  r  \leq b_2; \\ 0, & \text{if }  r  > b_2. \end{cases}$	$\frac{\tanh(r)}{r}$	$\frac{\delta^2}{\delta^2 + r^2}$
$\psi(r)$				
$L(r)$	$\begin{cases} r^2, & \text{if }  r  < \beta; \\ \beta r  - \frac{1}{2}\beta^2, & \text{if }  r  \geq \beta. \end{cases}$	$\begin{cases} r^2, & \text{if }  r  < b_1; \\ \frac{b_2 r^2 -  r ^3}{b_2 - b_1}, & \text{if } b_1 \leq  r  \leq b_2; \\ 0, & \text{if }  r  > b_2. \end{cases}$	$r \tanh(r)$	$\log(\delta^2 + r^2)$

### 3.3.7 Multiple output regression

In the case of multiple output data one can treat the different outputs separately. One can also let the toolbox do this by passing the right arguments. This case illustrates how to handle multiple outputs:

```
>> % load data in X, Xt and Y
>> % where size Y is N x 3
>>
>> gam = 1;
>> sig2 = 1;
>> [alpha,b] = trainlssvm({X,Y,'classification',gam,sig2});
>> Yhs = simlssvm({X,Y,'classification',gam,sig2},{alpha,b},Xt);
```

Using different kernel parameters per output dimension:

```
>> gam = 1;
>> sigs = [1 2 1.5];
>> [alpha,b] = trainlssvm({X,Y,'classification',gam,sigs});
>> Yhs = simlssvm({X,Y,'classification',gam,sigs},{alpha,b},Xt);
```

Tuning can be done per output dimension:

```
>> % tune the different parameters
>> [gam,sigs] = tunelssvm({X,Y,'classification',[],[],'RBF_kernel'},'simplex',...
    'crossvalidatelssvm',{10,'mse'});
```

### 3.3.8 A time-series example: Santa Fe laser data prediction

Using the static regression technique, a nonlinear feedforward prediction model can be built. The NARX model takes the past measurements as input to the model.

```
>> % load time-series in X and Xt
>> lag = 50;
>> Xu = windowize(X,1:lag+1);
>> Xtra = Xu(1:end-lag,1:lag); %training set
>> Ytra = Xu(1:end-lag,end); %training set
>> Xs=X(end-lag+1:end,1); %starting point for iterative prediction
```

Cross-validation is based upon feedforward simulation on the validation set using the feedforwardly trained model:

```
>> [gam,sig2] = tunelssvm({Xtra,Ytra,'f',[[],[]],'RBF_kernel'},'simplex',...
                        'crossvalidatelssvm',{10,'mae'});
```

Prediction of the next 100 points is done in a recurrent way:

```
>> [alpha,b] = trainlssvm({Xtra,Ytra,'f',gam,sig2,'RBF_kernel'});

>> %predict next 100 points
>> prediction = predict({Xtra,Ytra,'f',gam,sig2,'RBF_kernel'},Xs,100);
>> plot([prediction Xt]);
```

In Figure 3.13 results are shown for the Santa Fe laser data.

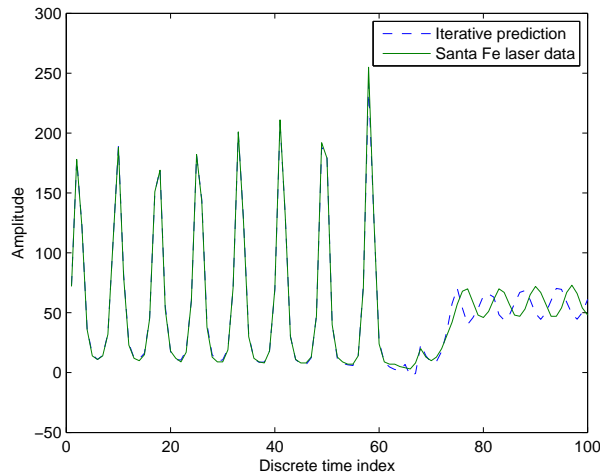


Figure 3.13: The solid line denotes the Santa Fe chaotic laser data. The dashed line shows the iterative prediction using LS-SVM with the RBF kernel with optimal hyper-parameters obtained by tuning.

### 3.3.9 Fixed size LS-SVM

The fixed size LS-SVM is based on two ideas (see also Section 2.4): the first is to exploit the primal-dual formulations of the LS-SVM in view of a Nyström approximation (Figure 3.14).

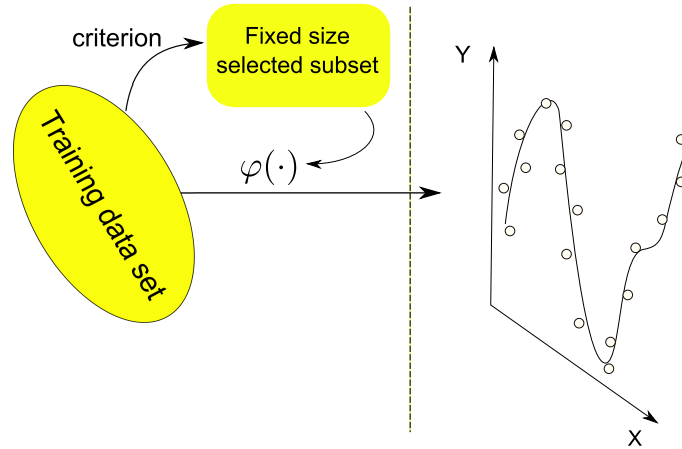


Figure 3.14: *Fixed Size LS-SVM is a method for solving large scale regression and classification problems. The number of support vectors is pre-fixed beforehand and the support vectors are selected from a pool of training data. After estimating eigenfunctions in relation to a Nyström approximation with selection of the support vectors according to an entropy criterion, the LS-SVM model is estimated in the primal space.*

The second one is to do active support vector selection (here based on entropy criteria). The first step is implemented as follows:

```
>> % X,Y contains the dataset, svX is a subset of X
>> sig2 = 1;
>> features = AFEm(svX,'RBF_kernel',sig2, X);
>> [Cl3, gam_optimal] = bay_rr(features,Y,1,3);
>> [W,b] = ridgeregress(features, Y, gam_optimal);
>> Yh = features*W+b;
```

Optimal values for the kernel parameters and the capacity of the fixed size LS-SVM can be obtained using a simple Monte Carlo experiment. For different kernel parameters and capacities (number of chosen support vectors), the performance on random subsets of support vectors are evaluated. The means of the performances are minimized by an exhaustive search (Figure 3.15b):

```
>> caps = [10 20 50 100 200]
>> sig2s = [.1 .2 .5 1 2 4 10]
>> nb = 10;
>> for i=1:length(caps),
    for j=1:length(sig2s),
        for t = 1:nb,
            sel = randperm(size(X,1));
            svX = X(sel(1:caps(i)));
            features = AFEm(svX,'RBF_kernel',sig2s(j), X);
            [Cl3, gam_opt] = bay_rr(features,Y,1,3);
            [W,b] = ridgeregress(features, Y, gam_opt);
            Yh = features*W+b;
            performances(t) = mse(Y - Yh);
        end
    end
end
```

```

    minimal_performances(i,j) = mean(performances);
end
end

```

The kernel parameter and capacity corresponding to a good performance are searched:

```

>> [minp,ic] = min(minimal_performances,[],1);
>> [minminp,is] = min(minp);
>> capacity = caps(ic);
>> sig2 = sig2s(is);

```

The following approach optimizes the selection of support vectors according to the quadratic Renyi entropy:

```

>> % load data X and Y, 'capacity' and the kernel parameter 'sig2'
>> sv = 1:capacity;
>> max_c = -inf;
>> for i=1:size(X,1),
    replace = ceil(rand.*capacity);
    subset = [sv([1:replace-1 replace+1:end]) i];
    crit = kentropy(X(subset,:), 'RBF_kernel', sig2);
    if max_c <= crit, max_c = crit; sv = subset; end
end

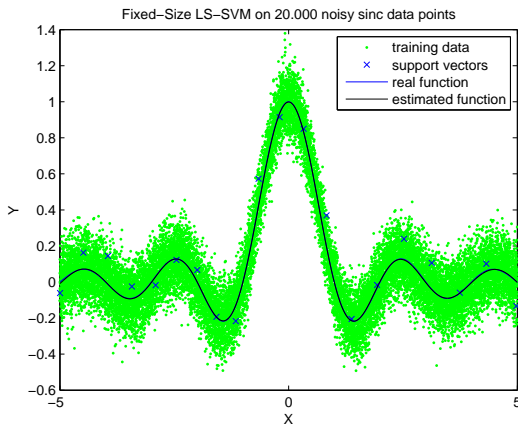
```

This selected subset of support vectors is used to construct the final model (Figure 3.15a):

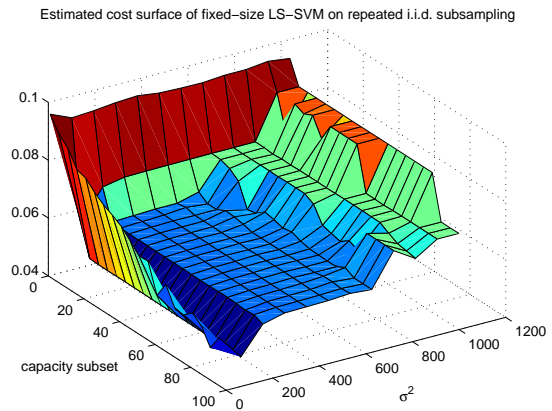
```

>> features = AFEm(svX, 'RBF_kernel', sig2, X);
>> [Cl3, gam_optimal] = bay_rr(features, Y, 1, 3);
>> [W, b, Yh] = ridgeregress(features, Y, gam_opt);

```



(a)



(b)

Figure 3.15: *Illustration of fixed size LS-SVM on a noisy sinc function with 20,000 data points: (a) fixed size LS-SVM selects a subset of the data after Nyström approximation. The regularization parameter for the regression in the primal space is optimized here using the Bayesian framework; (b) Estimated cost surface of the fixed size LS-SVM based on random subsamples of the data, of different subset capacities and kernel parameters.*

The same idea can be used for learning a classifier from a huge data set.

```
>> % load the input and output of the trasining data in X and Y
>> cap = 25;
```

The first step is the same: the selection of the support vectors by optimizing the entropy criterion. Here, the pseudo code is showed. For the working code, one can study the code of `demo_fixedclass.m`.

```
% initialise a subset of cap points: Xs
>> for i = 1:1000,
    Xs_old = Xs;
    % substitute a point of Xs by a new one

    crit = kentropy(Xs, kernel, kernel_par);

    % if crit is not larger then in the previous loop,
    % substitute Xs by the old Xs_old
end
```

By taking the values  $-1$  and  $+1$  as targets in a linear regression, the Fisher discriminant is obtained:

```
>> features = AFEm(Xs, kernel, sigma2, X);
>> [w, b] = ridgeregress(features, Y, gamma);
```

New data points can be simulated as follows:

```
>> features_t = AFEm(Xs, kernel, sigma2, Xt);
>> Yht = sign(features_t*w+b);
```

An example of a resulting classifier and the selected support vectors is displayed in Figure 3.16 (see `demo_fixedclass`).

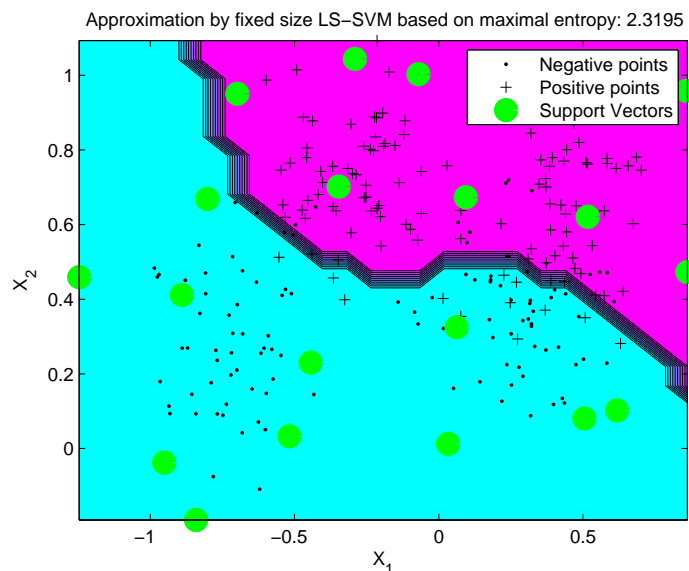


Figure 3.16: An example of a binary classifier (Ripley data set) obtained by application of a fixed size LS-SVM (20 support vectors) on a classification task.

### 3.4 Unsupervised learning using kernel principal component analysis

A simple example shows the idea of denoising in the input space by means of kernel PCA. The demo can be called by:

```
>> demo_yinyang
```

and uses the routine `preimage_rbf.m` which is a fixed-point iteration algorithm for computing pre-images in the case of RBF kernels. The pseudo-code is shown as follows:

```
>> % load training data in Xtrain and test data in Xtest
>> dim = size(Xtrain,2);
>> nb_pcs = 4;
>> factor = 0.25;
>> sig2 = factor*dim*mean(var(Xtrain)); % A rule of thumb for sig2;
>> [lam,U] = kpca(Xtrain,'RBF_kernel',sig2,Xtest,'eigs',nb_pcs);
```

The whole dataset is denoised by computing approximate pre-images:

```
>> Xd = preimage_rbf(X,sig2,U,[Xtrain;Xtest],'d');
```

Figure 3.17 shows the original dataset in gray ('+') and the denoised data in blue ('o'). Note that, the denoised data points preserve the underlying nonlinear structure of the data which is not the case in linear PCA.

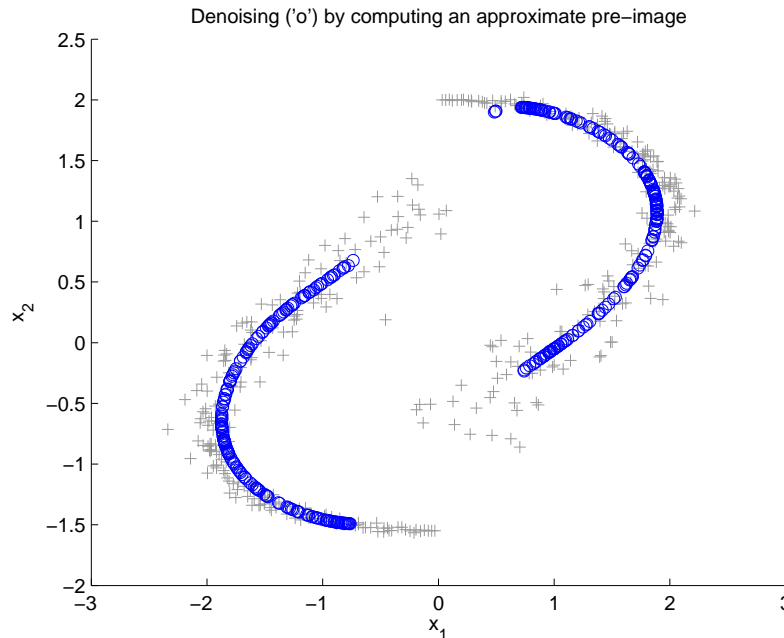


Figure 3.17: Denoised data ('o') obtained by reconstructing the data-points ('+') using 4 kernel principal components with the RBF kernel.

# Appendix A

## MATLAB functions

### A.1 General notation

In the full syntax description of the function calls, a star (\*) indicates that the argument is optional. In the description of the arguments, a (\*) denotes the default value. In this extended help of the function calls of LS-SVMlab, a number of symbols and notations return in the explanation and the examples. These are defined as follows:

<b>Variables</b>	<b>Explanation</b>
d	Dimension of the input vectors
empty	Empty matrix ([])
m	Dimension of the output vectors
N	Number of training data
Nt	Number of test data
nb	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation
X	$N \times d$ matrix with the inputs of the training data
Xt	$N_t \times d$ matrix with the inputs of the test data
Y	$N \times m$ matrix with the outputs of the training data
Yt	$N_t \times m$ matrix with the outputs of the test data
Zt	$N_t \times m$ matrix with the predicted latent variables of a classifier

This toolbox supports a classical functional interface as well as an object oriented interface. The latter has a few dedicated structures which will appear many times:

<b>Structures</b>	<b>Explanation</b>
bay	Object oriented representation of the results of the Bayesian inference
model	Object oriented representation of the LS-SVM model

## A.2 Index of function calls

### A.2.1 Training and simulation

Function Call	Short Explanation	Reference
<code>latentlssvm</code>	Calculate the latent variables of the LS-SVM classifier	A.3.20
<code>plotlssvm</code>	Plot the LS-SVM results in the environment of the training data	A.3.25
<code>simlssvm</code>	Evaluate the LS-SVM at the given points	A.3.34
<code>trainlssvm</code>	Find the support values and the bias term of a Least Squares Support Vector Machine	A.3.35
<code>lssvm</code>	One line LS-SVM	A.3.24
<code>cilssvm</code>	pointwise or simultaneous confidence intervals	A.3.9
<code>predlssvm</code>	pointwise or simultaneous prediction intervals	A.3.27



### A.2.2 Object oriented interface

This toolbox supports a classical functional interface as well as an object oriented interface. The latter has a few dedicated functions. This interface is recommended for the more experienced user.

Function Call	Short Explanation	Reference
<code>changelssvm</code>	Change properties of an LS-SVM object	A.3.16
<code>demomodel</code>	Demo introducing the use of the compact calls based on the model structure	
<code>initlssvm</code>	Initiate the LS-SVM object before training	A.3.16

### A.2.3 Training and simulating functions

Function Call	Short Explanation	Reference
<code>lssvmMATLAB.m</code>	MATLAB implementation of training	-
<code>prelssvm</code>	Internally called preprocessor	A.3.29
<code>postlssvm</code>	Internally called postprocessor	A.3.29

**A.2.4 Kernel functions**

<b>Function Call</b>	<b>Short Explanation</b>	<b>Reference</b>
<code>lin_kernel</code>	Linear kernel for MATLAB implementation	A.3.22
<code>poly_kernel</code>	Polynomial kernel for MATLAB implementation	A.3.22
<code>RBF_kernel</code>	Radial Basis Function kernel for MATLAB implementation	A.3.22
<code>MLP_kernel</code>	Multilayer Perceptron kernel for MATLAB implementation	A.3.22

### A.2.5 Tuning, sparseness and robustness

Function Call	Short Explanation	Reference
<code>crossvalidate</code>	Estimate the model performance with $L$ -fold crossvalidation	A.3.11
<code>gcrossvalidate</code>	Estimate the model performance with generalized crossvalidation	A.3.15
<code>rcrossvalidate</code>	Estimate the model performance with robust $L$ -fold crossvalidation	A.3.30
<code>gridsearch</code>	A two-dimensional minimization procedure based on exhaustive search in a limited range	A.3.36
<code>leaveoneout</code>	Estimate the model performance with leave-one-out crossvalidation	A.3.21
<code>mae, medae</code>	$L_1$ cost measures of the residuals	A.3.23
<code>linf, misclass</code>	$L_\infty$ and $L_0$ cost measures of the residuals	A.3.23
<code>mse</code>	$L_2$ cost measures of the residuals	A.3.23
<code>tunelssvm</code>	Tune the tuning parameters of the model with respect to the given performance measure	A.3.36
<code>robustlssvm</code>	Robust training in the case of non-Gaussian noise or outliers	A.3.32

## A.2.6 Classification extensions

Function Call	Short Explanation	Reference
<code>code</code>	Encode and decode a multi-class classification task to multiple binary classifiers	A.3.10
<code>code_ECOC</code>	Error correcting output coding	A.3.10
<code>code_MOC</code>	Minimum Output Coding	A.3.10
<code>code_OneVsAll</code>	One versus All encoding	A.3.10
<code>code_OneVsOne</code>	One versus One encoding	A.3.10
<code>codedist_hamming</code>	Hamming distance measure between two encoded class labels	A.3.10
<code>codeLSSVM</code>	Encoding the LS-SVM model	A.3.10
<code>deltaLSSVM</code>	Bias term correction for the LS-SVM classifier	A.3.12
<code>roc</code>	Receiver Operating Characteristic curve of a binary classifier	A.3.33

### A.2.7 Bayesian framework

Function Call	Short Explanation	Reference
<code>bay_errorbar</code>	Compute the error bars for a one dimensional regression problem	A.3.2
<code>bay_initlssvm</code>	Initialize the tuning parameters for Bayesian inference	A.3.3
<code>bay_lssvm</code>	Compute the posterior cost for the different levels in Bayesian inference	A.3.4
<code>bay_lssvmARD</code>	Automatic Relevance Determination of the inputs of the LS-SVM	A.3.5
<code>bay_modoutClass</code>	Estimate the posterior class probabilities of a binary classifier using Bayesian inference	A.3.6
<code>bay_optimize</code>	Optimize model- or tuning parameters with respect to the different inference levels	A.3.7
<code>bay_rr</code>	Bayesian inference for linear ridge regression	A.3.8
<code>eign</code>	Find the principal eigenvalues and eigenvectors of a matrix with Nyström's low rank approximation method	A.3.14
<code>kernel_matrix</code>	Construct the positive (semi-) definite kernel matrix	A.3.18
<code>kpca</code>	Kernel Principal Component Analysis	A.3.19
<code>ridgeregress</code>	Linear ridge regression	A.3.31

**A.2.8 NARX models and prediction**

<b>Function Call</b>	<b>Short Explanation</b>	<b>Reference</b>
<code>predict</code>	Iterative prediction of a trained LS-SVM NARX model (in recurrent mode)	A.3.26
<code>windowize</code>	Rearrange the data points into a Hankel matrix for (N)AR time-series modeling	A.3.37
<code>windowize_NARX</code>	Rearrange the input and output data into a (block) Hankel matrix for (N)AR(X) time-series modeling	A.3.37

### A.2.9 Unsupervised learning

Function Call	Short Explanation	Reference
<code>AFEm</code>	Automatic Feature Extraction from Nyström method	A.3.1
<code>denoise_kpca</code>	Reconstruct the data mapped on the principal components	A.3.13
<code>kentropy</code>	Quadratic Renyi Entropy for a kernel based estimator	A.3.17
<code>kpca</code>	Compute the nonlinear kernel principal components of the data	A.3.19
<code>preimage_rbf</code>	Compute an approximate pre-image in the input space (for RBF kernels)	A.3.28



### A.2.10 Fixed size LS-SVM

The idea of fixed size LS-SVM is still under development. However, in order to enable the user to explore this technique a number of related functions are included in the toolbox. A demo illustrates how to combine these in order to build a fixed size LS-SVM.

Function Call	Short Explanation	Reference
<code>AFEm</code>	Automatic Feature Extraction from Nyström method	A.3.1
<code>bay_rr</code>	Bayesian inference of the cost on the 3 levels of linear ridge regression	A.3.8
<code>demo_fixedsize</code>	Demo illustrating the use of fixed size LS-SVMs for regression	-
<code>demo_fixedclass</code>	Demo illustrating the use of fixed size LS-SVMs for classification	-
<code>kentropy</code>	Quadratic Renyi Entropy for a kernel based estimator	A.3.17
<code>ridgeregress</code>	Linear ridge regression	A.3.31

**A.2.11 Demos**

<b>name of the demo</b>	<b>Short Explanation</b>
<code>demofun</code>	Simple demo illustrating the use of LS-SVMlab for regression
<code>demo_fixedsize</code>	Demo illustrating the use of fixed size LS-SVMs for regression
<code>democlass</code>	Simple demo illustrating the use of LS-SVMlab for classification
<code>demo_fixedclass</code>	Demo illustrating the use of fixed size LS-SVMs for classification
<code>demomodel</code>	Simple demo illustrating the use of the object oriented interface of LS-SVMlab
<code>demo_yinyang</code>	Demo illustrating the possibilities of unsupervised learning by kernel PCA
<code>democonfint</code>	Demo illustrating the construction of confidence intervals for LS-SVMs (regression)

## A.3 Alphabetical list of function calls

### A.3.1 AFEm

#### Purpose

*Automatic Feature Extraction by Nyström method*

#### Basic syntax

```
>> features = AFEm(X, kernel, sig2, Xt)
```

#### Description

Using the *Nyström* approximation method, the mapping of data to the feature space can be evaluated explicitly. This gives features that one can use for a parametric regression or classification in the primal space. The decomposition of the mapping to the feature space relies on the eigenvalue decomposition of the kernel matrix. The Matlab ('eigs') or Nyström's ('eign') approximation using the **nb** most important eigenvectors/eigenvalues can be used. The eigenvalue decomposition is not re-calculated if it is passed as an extra argument.

#### Full syntax

```
>> [features, U, lam] = AFEm(X, kernel, sig2, Xt)
>> [features, U, lam] = AFEm(X, kernel, sig2, Xt, etype)
>> [features, U, lam] = AFEm(X, kernel, sig2, Xt, etype, nb)
>> features           = AFEm(X, kernel, sig2, Xt, [], [], U, lam)
```

#### Outputs

<b>features</b>	<b>Nt</b> × <b>nb</b> matrix with extracted features
<b>U(*)</b>	<b>N</b> × <b>nb</b> matrix with eigenvectors
<b>lam(*)</b>	<b>nb</b> ×1 vector with eigenvalues

#### Inputs

<b>X</b>	<b>N</b> × <b>d</b> matrix with input data
<b>kernel</b>	Name of the used kernel (e.g. 'RBF_kernel')
<b>sig2</b>	Kernel parameter(s) (for linear kernel, use [])
<b>Xt</b>	<b>Nt</b> × <b>d</b> data from which the features are extracted
<b>etype(*)</b>	'eig'(*), 'eigs' or 'eign'
<b>nb(*)</b>	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation
<b>U(*)</b>	<b>N</b> × <b>nb</b> matrix with eigenvectors
<b>lam(*)</b>	<b>nb</b> ×1 vector with eigenvalues

#### See also:

kernel\_matrix, RBF\_kernel, demo\_fixedsize

### A.3.2 bay\_errorbar

#### Purpose

*Compute the error bars for a one dimensional regression problem*

#### Basic syntax

```
>> sig_e = bay_errorbar({X,Y,'function',gam,sig2}, Xt)
>> sig_e = bay_errorbar(model, Xt)
```

#### Description

The computation takes into account the estimated noise variance and the uncertainty of the model parameters, estimated by Bayesian inference. `sig_e` is the estimated standard deviation of the error bars of the points `Xt`. A plot is obtained by replacing `Xt` by the string `'figure'`.

#### Full syntax

- Using the functional interface:

```
>> sig_e = bay_errorbar({X,Y,'function',gam,sig2,kernel,preprocess}, Xt)
>> sig_e = bay_errorbar({X,Y,'function',gam,sig2,kernel,preprocess}, Xt, etype)
>> sig_e = bay_errorbar({X,Y,'function',gam,sig2,kernel,preprocess}, Xt, etype, nb)
>> sig_e = bay_errorbar({X,Y,'function',gam,sig2,kernel,preprocess}, 'figure')
>> sig_e = bay_errorbar({X,Y,'function',gam,sig2,kernel,preprocess}, 'figure', etype, nb)
```

#### Outputs

`sig_e`                       $N_t \times 1$  vector with the  $\sigma^2$  error bars of the test data

#### Inputs

<code>X</code>	$N \times d$ matrix with the inputs of the training data
<code>Y</code>	$N \times 1$ vector with the inputs of the training data
<code>type</code>	<code>'function estimation'</code> ( <code>'f'</code> )
<code>gam</code>	Regularization parameter
<code>sig2</code>	Kernel parameter
<code>kernel(*)</code>	Kernel type (by default <code>'RBF_kernel'</code> )
<code>preprocess(*)</code>	<code>'preprocess'(*)</code> or <code>'original'</code>
<code>Xt</code>	$N_t \times d$ matrix with the inputs of the test data
<code>etype(*)</code>	<code>'svd'(*)</code> , <code>'eig'</code> , <code>'eigs'</code> or <code>'eign'</code>
<code>nb(*)</code>	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

- Using the object oriented interface:

```
>> [sig_e, bay, model] = bay_errorbar(model, Xt)
>> [sig_e, bay, model] = bay_errorbar(model, Xt, etype)
>> [sig_e, bay, model] = bay_errorbar(model, Xt, etype, nb)
>> [sig_e, bay, model] = bay_errorbar(model, 'figure')
>> [sig_e, bay, model] = bay_errorbar(model, 'figure', etype)
>> [sig_e, bay, model] = bay_errorbar(model, 'figure', etype, nb)
```

**Outputs**

<code>sig_e</code>	$N_t \times 1$ vector with the $\sigma^2$ error bars of the test data
<code>model(*)</code>	Object oriented representation of the LS-SVM model
<code>bay(*)</code>	Object oriented representation of the results of the Bayesian inference

**Inputs**

<code>model</code>	Object oriented representation of the LS-SVM model
<code>Xt</code>	$N_t \times d$ matrix with the inputs of the test data
<code>etype(*)</code>	'svd'(*), 'eig', 'eigs' or 'eign'
<code>nb(*)</code>	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

**See also:**

`bay_lssvm`, `bay_optimize`, `bay_modoutClass`, `plotlssvm`

### A.3.3 bay\_initlssvm

#### Purpose

*Initialize the tuning parameters  $\gamma$  and  $\sigma^2$  before optimization with bay\_optimize*

#### Basic syntax

```
>> [gam, sig2] = bay_initlssvm({X,Y,type,[],[]})
>> model      = bay_initlssvm(model)
```

#### Description

A starting value for  $\sigma^2$  is only given if the model has kernel type 'RBF\_kernel'.

#### Full syntax

- Using the functional interface:

```
>> [gam, sig2] = bay_initlssvm({X,Y,type,[],[],kernel})
```

#### Outputs

gam	Proposed initial regularization parameter
sig2	Proposed initial 'RBF_kernel' parameter

#### Inputs

X	N×d matrix with the inputs of the training data
Y	N×1 vector with the outputs of the training data
type	'function estimation' ('f') or 'classifier' ('c')
kernel(*)	Kernel type (by default 'RBF_kernel')

- Using the object oriented interface:

```
>> model = bay_initlssvm(model)
```

#### Outputs

model	Object oriented representation of the LS-SVM model with initial tuning parameters
-------	---

#### Inputs

model	Object oriented representation of the LS-SVM model
-------	--

See also:

bay\_lssvm, bay\_optimize

### A.3.4 bay\_lssvm

#### Purpose

*Compute the posterior cost for the 3 levels in Bayesian inference*

#### Basic syntax

```
>> cost = bay_lssvm({X,Y,type,gam,sig2}, level, etype)
>> cost = bay_lssvm(model, level, etype)
```

#### Description

Estimate the posterior probabilities of model tuning parameters on the different inference levels. By taking the negative logarithm of the posterior and neglecting all constants, one obtains the corresponding cost.

Computation is only feasible for one dimensional output regression and binary classification problems. Each level has its different input and output syntax:

- **First level:** The cost associated with the posterior of the model parameters (support values and bias term) is determined. The type can be:
  - **'train'**: do a training of the support values using `trainlssvm`. The total cost, the cost of the residuals (`Ed`) and the regularization parameter (`Ew`) are determined by the solution of the support values
  - **'retrain'**: do a retraining of the support values using `trainlssvm`
  - the cost terms can also be calculated from an (approximate) eigenvalue decomposition of the kernel matrix: **'svd'**, **'eig'**, **'eigs'** or Nyström's **'eign'**
- **Second level:** The cost associated with the posterior of the regularization parameter is computed. The etype can be **'svd'**, **'eig'**, **'eigs'** or Nyström's **'eign'**.
- **Third level:** The cost associated with the posterior of the chosen kernel and kernel parameters is computed. The etype can be: **'svd'**, **'eig'**, **'eigs'** or Nyström's **'eign'**.

#### Full syntax

- **Outputs on the first level**

```
>> [costL1,Ed,Ew,bay] = bay_lssvm({X,Y,type,gam,sig2,kernel,preprocess}, 1)
>> [costL1,Ed,Ew,bay] = bay_lssvm({X,Y,type,gam,sig2,kernel,preprocess}, 1, etype)
>> [costL1,Ed,Ew,bay] = bay_lssvm({X,Y,type,gam,sig2,kernel,preprocess}, 1, etype, nb)
>> [costL1,Ed,Ew,bay] = bay_lssvm(model, 1)
>> [costL1,Ed,Ew,bay] = bay_lssvm(model, 1, etype)
>> [costL1,Ed,Ew,bay] = bay_lssvm(model, 1, etype, nb)
```

With

<code>costL1</code>	Cost proportional to the posterior
<code>Ed(*)</code>	Cost of the training error term
<code>Ew(*)</code>	Cost of the regularization parameter
<code>bay(*)</code>	Object oriented representation of the results of the Bayesian inference

- **Outputs on the second level**

```
>> [costL2,DcostL2, optimal_cost, bay] = ...
    bay_lssvm({X,Y,type,gam,sig2,kernel,preprocess}, 2, etype, nb)
>> [costL2,DcostL2, optimal_cost, bay] = bay_lssvm(model, 2, etype, nb)
```

With

costL2	Cost proportional to the posterior on the second level
DcostL2(*)	Derivative of the cost
optimal_cost(*)	Optimality of the regularization parameter (optimal = 0)
bay(*)	Object oriented representation of the results of the Bayesian inference

#### • Outputs on the third level

```
>> [costL3,bay] = bay_lssvm({X,Y,type,gam,sig2,kernel,preprocess}, 3, etype, nb)
>> [costL3,bay] = bay_lssvm(model, 3, etype, nb)
```

With

costL3	Cost proportional to the posterior on the third level
bay(*)	Object oriented representation of the results of the Bayesian inference

#### • Inputs using the functional interface

```
>> bay_lssvm({X,Y,type,gam,sig2,kernel,preprocess}, level, etype, nb)
```

X	N×d matrix with the inputs of the training data
Y	N×1 vector with the outputs of the training data
type	'function estimation' ('f') or 'classifier' ('c')
gam	Regularization parameter
sig2	Kernel parameter(s) (for linear kernel, use [])
kernel(*)	Kernel type (by default 'RBF_kernel')
preprocess(*)	'preprocess'(*) or 'original'
level	1, 2, 3
etype(*)	'svd'(*), 'eig', 'eigs', 'eign'
nb(*)	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

#### • Inputs using the object oriented interface

```
>> bay_lssvm(model, level, etype, nb)
```

model	Object oriented representation of the LS-SVM model
level	1, 2, 3
etype(*)	'svd'(*), 'eig', 'eigs', 'eign'
nb(*)	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

See also:

bay\_lssvmARD, bay\_optimize, bay\_modoutClass, bay\_errorbar



### A.3.5 bay\_lssvmARD

#### Purpose

*Bayesian Automatic Relevance Determination of the inputs of an LS-SVM*

#### Basic syntax

```
>> dimensions = bay_lssvmARD({X,Y,type,gam,sig2})
>> dimensions = bay_lssvmARD(model)
```

#### Description

For a given problem, one can determine the most relevant inputs for the LS-SVM within the Bayesian evidence framework. To do so, one assigns a different weighting parameter to each dimension in the kernel and optimizes this using the third level of inference. According to the used kernel, one can remove inputs based on the larger or smaller kernel parameters. This routine *only* works with the 'RBF\_kernel' with a **sig2** per input. In each step, the input with the largest optimal **sig2** is removed (backward selection). For every step, the generalization performance is approximated by the cost associated with the third level of Bayesian inference.

The ARD is based on backward selection of the inputs based on the **sig2s** corresponding in each step with a minimal cost criterion. Minimizing this criterion can be done by 'continuous' or by 'discrete'. The former uses in each step continuous varying kernel parameter optimization, the latter decides which one to remove in each step by binary variables for each component (this can only be applied for rather low dimensional inputs as the number of possible combinations grows exponentially with the number of inputs). If working with the 'RBF\_kernel', the kernel parameter is rescaled appropriately after removing an input variable.

The computation of the Bayesian cost criterion can be based on the singular value decomposition 'svd' of the full kernel matrix or by an approximation of these eigenvalues and vectors by the 'eigs' or 'eign' approximation based on 'nb' data points.

#### Full syntax

- Using the functional interface:

```
>> [dimensions, ordered, costs, sig2s] = ...
    bay_lssvmARD({X,Y,type,gam,sig2,kernel,preprocess}, method, etype, nb)
```

#### Outputs

<b>dimensions</b>	$r \times 1$ vector of the relevant inputs
<b>ordered(*)</b>	$d \times 1$ vector with inputs in decreasing order of relevance
<b>costs(*)</b>	Costs associated with third level of inference in every selection step
<b>sig2s(*)</b>	Optimal kernel parameters in each selection step

#### Inputs

<b>X</b>	$N \times d$ matrix with the inputs of the training data
<b>Y</b>	$N \times 1$ vector with the outputs of the training data
<b>type</b>	'function estimation' ('f') or 'classifier' ('c')
<b>gam</b>	Regularization parameter
<b>sig2</b>	Kernel parameter(s) (for linear kernel, use [])
<b>kernel(*)</b>	Kernel type (by default 'RBF_kernel')
<b>preprocess(*)</b>	'preprocess'(*) or 'original'
<b>method(*)</b>	'discrete'(*) or 'continuous'
<b>etype(*)</b>	'svd'(*), 'eig', 'eigs', 'eign'
<b>nb(*)</b>	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

- Using the object oriented interface:

```
>> [dimensions, ordered, costs, sig2s, model] = bay_lssvmARD(model, method, etype, nb)
```

### Outputs

<code>dimensions</code>	<code>r</code> × <code>1</code> vector of the relevant inputs
<code>ordered(*)</code>	<code>d</code> × <code>1</code> vector with inputs in decreasing order of relevance
<code>costs(*)</code>	Costs associated with third level of inference in every selection step
<code>sig2s(*)</code>	Optimal kernel parameters in each selection step
<code>model(*)</code>	Object oriented representation of the LS-SVM model trained only on the relevant inputs

### Inputs

<code>model</code>	Object oriented representation of the LS-SVM model
<code>method(*)</code>	'discrete'(*) or 'continuous'
<code>etype(*)</code>	'svd'(*), 'eig', 'eigs', 'eign'
<code>nb(*)</code>	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

### See also:

`bay_lssvm`, `bay_optimize`, `bay_modoutClass`, `bay_errorbar`

**A.3.6 bay\_modoutClass****Purpose**

*Estimate the posterior class probabilities of a binary classifier using Bayesian inference*

**Basic syntax**

```
>> [Ppos, Pneg] = bay_modoutClass({X,Y,'classifier',gam,sig2}, Xt)
>> [Ppos, Pneg] = bay_modoutClass(model, Xt)
```

**Description**

Calculate the probability that a point will belong to the positive or negative classes taking into account the uncertainty of the parameters. Optionally, one can express prior knowledge as a probability between 0 and 1, where prior equal to 2/3 means that the prior positive class probability is 2/3 (more likely to occur than the negative class).

For binary classification tasks with a two dimensional input space, one can make a surface plot by replacing `Xt` by the string `'figure'`.

**Full syntax**

- Using the functional interface:

```
>> [Ppos, Pneg] = bay_modoutClass({X,Y,'classifier',...
    gam,sig2, kernel, preprocess}, Xt)
>> [Ppos, Pneg] = bay_modoutClass({X,Y,'classifier',...
    gam,sig2, kernel, preprocess}, Xt, prior)
>> [Ppos, Pneg] = bay_modoutClass({X,Y,'classifier',...
    gam,sig2, kernel, preprocess}, Xt, prior, etype)
>> [Ppos, Pneg] = bay_modoutClass({X,Y,'classifier',...
    gam,sig2, kernel, preprocess}, Xt, prior, etype, nb)
>> bay_modoutClass({X,Y,'classifier',...
    gam,sig2, kernel, preprocess}, 'figure')
>> bay_modoutClass({X,Y,'classifier',...
    gam,sig2, kernel, preprocess}, 'figure', prior)
>> bay_modoutClass({X,Y,'classifier',...
    gam,sig2, kernel, preprocess}, 'figure', prior, etype)
>> bay_modoutClass({X,Y,'classifier',...
    gam,sig2, kernel, preprocess}, 'figure', prior, etype, nb)
```

**Outputs**

<b>Ppos</b>	$N_t \times 1$ vector with probabilities that testdata <b>Xt</b> belong to the positive class
<b>Pneg</b>	$N_t \times 1$ vector with probabilities that testdata <b>Xt</b> belong to the negative(zero) class

**Inputs**

<b>X</b>	$N \times d$ matrix with the inputs of the training data
<b>Y</b>	$N \times 1$ vector with the outputs of the training data
<b>type</b>	'function estimation' ('f') or 'classifier' ('c')
<b>gam</b>	Regularization parameter
<b>sig2</b>	Kernel parameter(s) (for linear kernel, use [])
<b>kernel(*)</b>	Kernel type (by default 'RBF_kernel')
<b>preprocess(*)</b>	'preprocess'(*) or 'original'
<b>Xt(*)</b>	$N_t \times d$ matrix with the inputs of the test data
<b>prior(*)</b>	Prior knowledge of the balancing of the training data (or [])
<b>etype(*)</b>	'svd'(*), 'eig', 'eigs' or 'eign'
<b>nb(*)</b>	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

- Using the object oriented interface:

```
>> [Ppos, Pneg, bay, model] = bay_modoutClass(model, Xt)
>> [Ppos, Pneg, bay, model] = bay_modoutClass(model, Xt, prior)
>> [Ppos, Pneg, bay, model] = bay_modoutClass(model, Xt, prior, etype)
>> [Ppos, Pneg, bay, model] = bay_modoutClass(model, Xt, prior, etype, nb)
>> bay_modoutClass(model, 'figure')
>> bay_modoutClass(model, 'figure', prior)
>> bay_modoutClass(model, 'figure', prior, etype)
>> bay_modoutClass(model, 'figure', prior, etype, nb)
```

**Outputs**

<b>Ppos</b>	$N_t \times 1$ vector with probabilities that testdata <b>Xt</b> belong to the positive class
<b>Pneg</b>	$N_t \times 1$ vector with probabilities that testdata <b>Xt</b> belong to the negative(zero) class
<b>bay(*)</b>	Object oriented representation of the results of the Bayesian inference
<b>model(*)</b>	Object oriented representation of the LS-SVM model

**Inputs**

<b>model</b>	Object oriented representation of the LS-SVM model
<b>Xt(*)</b>	$N_t \times d$ matrix with the inputs of the test data
<b>prior(*)</b>	Prior knowledge of the balancing of the training data (or [])
<b>etype(*)</b>	'svd'(*), 'eig', 'eigs' or 'eign'
<b>nb(*)</b>	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

See also:

bay\_lssvm, bay\_optimize, bay\_errorbar, ROC

### A.3.7 bay\_optimize

#### Purpose

*Optimize the posterior probabilities of model (hyper-) parameters with respect to the different levels in Bayesian inference*

#### Basic syntax

One can optimize on the three different inference levels as described in section 2.1.3.

- **First level:** In the first level one optimizes the support values  $\alpha$ 's and the bias  $b$ .
- **Second level:** In the second level one optimizes the regularization parameter  $\text{gam}$ .
- **Third level:** In the third level one optimizes the kernel parameter. In the case of the common 'RBF\_kernel' the kernel parameter is the bandwidth  $\text{sig2}$ .

*This routine is only tested with Matlab R2008a, R2008b, R2009a, R2009b and R2010a using the corresponding optimization toolbox.*

#### Full syntax

- **Outputs on the first level:**

```
>> [model, alpha, b] = bay_optimize({X,Y,type,gam,sig2,kernel,preprocess}, 1)
>> [model, alpha, b] = bay_optimize(model, 1)
```

With

<code>model</code>	Object oriented representation of the LS-SVM model optimized on the first level of inference
<code>alpha(*)</code>	Support values optimized on the first level of inference
<code>b(*)</code>	Bias term optimized on the first level of inference

- **Outputs on the second level:**

```
>> [model,gam] = bay_optimize({X,Y,type,gam,sig2,kernel,preprocess}, 2)
>> [model,gam] = bay_optimize(model, 2)
```

With

<code>model</code>	Object oriented representation of the LS-SVM model optimized on the second level of inference
<code>gam(*)</code>	Regularization parameter optimized on the second level of inference

- **Outputs on the third level:**

```
>> [model, sig2] = bay_optimize({X,Y,type,gam,sig2,kernel,preprocess}, 3)
>> [model, sig2] = bay_optimize(model, 3)
```

With

<code>model</code>	Object oriented representation of the LS-SVM model optimized on the third level of inference
<code>sig2(*)</code>	Kernel parameter optimized on the third level of inference

- **Inputs using the functional interface**

```
>> model = bay_optimize({X,Y,type,gam,sig2,kernel,preprocess}, level)
>> model = bay_optimize({X,Y,type,gam,sig2,kernel,preprocess}, level, etype)
>> model = bay_optimize({X,Y,type,gam,sig2,kernel,preprocess}, level, etype, nb)
```

X	N×d matrix with the inputs of the training data
Y	N×1 vector with the outputs of the training data
type	'function estimation' ('f') or 'classifier' ('c')
gam	Regularization parameter
sig2	Kernel parameter(s) (for linear kernel, use [])
kernel(*)	Kernel type (by default 'RBF_kernel')
preprocess(*)	'preprocess'(*) or 'original'
level	1, 2, 3
etype(*)	'eig', 'svd'(*), 'eigs', 'eign'
nb(*)	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

• Inputs using the object oriented interface

```
>> model = bay_optimize(model, level)
>> model = bay_optimize(model, level, etype)
>> model = bay_optimize(model, level, etype, nb)
```

model	Object oriented representation of the LS-SVM model
level	1, 2, 3
etype(*)	'eig', 'svd'(*), 'eigs', 'eign'
nb(*)	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

See also:

bay\_lssvm, bay\_lssvmARD, bay\_modoutClass, bay\_errorbar

### A.3.8 bay\_rr

#### Purpose

*Bayesian inference of the cost on the three levels of linear ridge regression*

#### Basic syntax

```
>> cost = bay_rr(X, Y, gam, level)
```

#### Description

This function implements the cost functions related to the Bayesian framework of linear ridge Regression [44]. Optimizing these criteria results in optimal model parameters  $\mathbf{W}, \mathbf{b}$  and tuning parameters. The criterion can also be used for model comparison. The obtained model parameters  $\mathbf{w}$  and  $\mathbf{b}$  are optimal on the first level for  $J = 0.5 \cdot \mathbf{w}' \cdot \mathbf{w} + \text{gam} \cdot 0.5 \cdot \text{sum}(\mathbf{Y} - \mathbf{X} \cdot \mathbf{w} - \mathbf{b})^2$ .

#### Full syntax

- **Outputs on the first level:** Cost proportional to the posterior of the model parameters.

```
>> [costL1, Ed, Ew] = bay_rr(X, Y, gam, 1)
```

With

costL1	Cost proportional to the posterior
Ed(*)	Cost of the training error term
Ew(*)	Cost of the regularization parameter

- **Outputs on the second level:** Cost proportional to the posterior of  $\text{gam}$ .

```
>> [costL2, DcostL2, Deff, mu, ksi, eigval, eigvec] = bay_rr(X, Y, gam, 2)
```

With

costL2	Cost proportional to the posterior on the second level
DcostL2(*)	Derivative of the cost proportional to the posterior
Deff(*)	Effective number of parameters
mu(*)	Relative importance of the fitting error term
ksi(*)	Relative importance of the regularization parameter
eigval(*)	Eigenvalues of the covariance matrix
eigvec(*)	Eigenvectors of the covariance matrix

- **Outputs on the third level:** The following commands can be used to compute the level 3 cost function for different models (e.g. models with different selected sets of inputs). The best model can then be chosen as the model with best level 3 cost (**CostL3**).

```
>> [costL3, gam_optimal] = bay_rr(X, Y, gam, 3)
```

With

costL3	Cost proportional to the posterior on the third inference level
gam_optimal(*)	Optimal regularization parameter obtained from optimizing the second level

- **Inputs:**

```
>> cost = bay_rr(X, Y, gam, level)
```

X	N×d matrix with the inputs of the training data
Y	N×1 vector with the outputs of the training data
gam	Regularization parameter
level	1, 2, 3

**See also:**

ridgeregress, bay\_lssvm



**A.3.9 cilssvm****Purpose**

*Construction of bias corrected  $100(1 - \alpha)\%$  pointwise or simultaneous confidence intervals*

**Basic syntax**

```
>> ci = cilssvm({X,Y,type,gam,kernel_par,kernel,preprocess},alpha,confdtype)
>> ci = cilssvm(model,alpha,confdtype)
```

**Description**

This function calculates bias corrected  $100(1 - \alpha)\%$  pointwise or simultaneous confidence intervals. The procedure support homoscedastic data sets as well heteroscedastic data sets. The construction of the confidence intervals are based on the central limit theorem for linear smoothers combined with bias correction and variance estimation.

**Full syntax**

- Using the functional interface:

```
>> ci = cilssvm({X,Y,type,gam,kernel_par,kernel,preprocess})
>> ci = cilssvm({X,Y,type,gam,kernel_par,kernel,preprocess}, alpha)
>> ci = cilssvm({X,Y,type,gam,kernel_par,kernel,preprocess}, alpha, confdtype)
```

**Outputs**

ci  $N \times 2$  matrix containing the lower and upper confidence intervals

**Inputs**

X	Training input data used for defining the LS-SVM and the preprocessing
Y	Training output data used for defining the LS-SVM and the preprocessing
type	'function estimation' ('f') or 'classifier' ('c')
gam	Regularization parameter
sig2	Kernel parameter(s) (for linear kernel, use [])
kernel(*)	Kernel type (by default 'RBF_kernel')
preprocess(*)	'preprocess'(*) or 'original'
alpha(*)	Significance level (by default 5%)
confdtype(*)	Type of confidence interval 'pointwise' or 'simultaneous' (by default 'simultaneous')

- Using the object oriented interface:

```
>> ci = cilssvm(model)
>> ci = cilssvm(model, alpha)
>> ci = cilssvm(model, alpha, confdtype)
```

**Outputs**

ci  $N \times 2$  matrix containing the lower and upper confidence intervals

**Inputs**

model	Object oriented representation of the LS-SVM model
alpha(*)	Significance level (by default 5%)
confdtype(*)	Type of confidence interval 'pointwise' or 'simultaneous' (by default simultaneous)

**See also:**

trainlssvm, simlssvm, predlssvm

### A.3.10 `code`, `code1ssvm`

#### Purpose

*Encode and decode a multi-class classification task into multiple binary classifiers*

#### Basic syntax

```
>> Yc = code(Y, codebook)
```

#### Description

The coding is defined by the codebook. The codebook is represented by a matrix where the columns represent all different classes and the rows indicate the result of the binary classifiers. An example is given: the 3 classes with original labels [1 2 3] can be encoded in the following codebook (using Minimum Output Coding):

```
>> codebook
    = [-1  -1  1;
        1  -1  1]
```

For this codebook, a member of the first class is found if the first binary classifier is negative and the second classifier is positive. A *don't care* is represented by NaN. By default it is assumed that the original classes are represented as different numerical labels. One can overrule this by passing the `old_codebook` which contains information about the old representation.

A codebook can be created by one of the functions (`codefct`) `code_MOC`, `code_OneVsOne`, `code_OneVsAll`, `code_ECOC`. Additional arguments to this function can be passed as a cell in `codefct_args`.

```
>> Yc = code(Y,codefct,codefct_args)
>> Yc = code(Y,codefct,codefct_args, old_codebook)
>> [Yc, codebook, oldcodebook] = code(Y,codefct,codefct_args)
```

To detect the classes of a disturbed encoded signal given the corresponding codebook, one needs a distance function (`fctdist`) with optional arguments given as a cell (`fctdist_args`). By default, the Hamming distance (of function `codedist_hamming`) is used.

```
>> Yc = code(Y, codefct, codefct_args, old_codebook, fctdist, fctdist_args)
```

A simple example is given here, a more elaborated example is given in section 3.2.6. Here, a short categorical signal `Y` is encoded in `Yec` using Minimum Output Coding and decoded again to its original form:

```
>> Y = [1; 2; 3; 2; 1]
>> [Yc,codebook,old_codebook] = code(Y,'code_MOC')           % encode
>> Yc
    = [-1    -1
        -1     1
         1    -1
        -1     1
        -1    -1]

>> codebook
    = [ -1    -1     1
        -1     1    -1]

>> old_codebook
    = [1     2     3]
```

```
>> code(Yc, old_codebook, [], codebook, 'codedist_hamming') % decode
ans
= [1; 2; 3; 2; 1]
```

Different encoding schemes are available:

- **Minimum Output Coding** (`code_MOC`)

Here the minimal number of bits  $n_b$  is used to encode the  $n_c$  classes:

$$n_b = \lceil \log_2 n_c \rceil.$$

- **Error Correcting Output Code** (`code_ECOC`)

This coding scheme uses redundant bits. Typically, one bounds the number of binary classifiers  $n_b$  by

$$n_b \leq 15 \lceil \log_2 n_c \rceil.$$

However, it is not guaranteed to have a valid  $n_b$ -representation of  $n_c$  classes for all combinations. This routine based on backtracking can take some memory and time.

- **One versus All Coding** (`code_OneVsAll`)

Each binary classifier  $k = 1, \dots, n_c$  is trained to discriminate between class  $k$  and the union of the others.

- **One Versus One Coding** (`code_OneVsOns`)

Each of the  $n_b$  binary classifiers is used to discriminate between a specific pair of  $n_c$  classes

$$n_b = \frac{n_c(n_c - 1)}{2}.$$

Different decoding schemes are implemented:

- **Hamming Distance** (`codedist_hamming`)

This measure equals the number of corresponding bits in the binary result and the codeword. Typically, it is used for the Error Correcting Code.

- **Bayesian Distance Measure** (`codedist_bay`)

The Bayesian moderated output of the binary classifiers is used to estimate the posterior probability.

Encoding using the previous algorithms of the LS-SVM multi-class classifier can easily be done by `codeLSSVM`. It will be invoked by `trainLSSVM` if an appropriate encoding scheme is defined in a model. An example shows how to use the Bayesian distance measure to extract the estimated class from the simulated encoded signal. Assumed are input and output data **X** and **Y** (size is respectively  $N_{train} \times D_{in}$  and  $N_{train} \times 1$ ), a kernel parameter `sig2` and a regularization parameter `gam`. **Yt** corresponding to a set of data points **Xt** (size is  $N_{test} \times D_{in}$ ) is to be estimated:

```
% encode for training
>> model = initLSSVM(X, Y, 'classifier', gam, sig2)
>> model = changeLSSVM(model, 'codetype', 'code_MOC')
>> model = changeLSSVM(model, 'codedist_fct', 'codedist_hamming')
>> model = codeLSSVM(model) % implicitly called by next command
>> model = trainLSSVM(model)
>> plotLSSVM(model);

% decode for simulating
>> model = changeLSSVM(model, 'codedist_fct', 'codedist_bay')
>> model = changeLSSVM(model, 'codedist_args', ...
                        {bay_modoutClass(model,Xt)})
>> Yt = simLSSVM(model, Xt)
```

**Full syntax**

We denote the number of used binary classifiers by `nbits` and the number of different represented classes by `nc`.

- For encoding:

```
>> [Yc, codebook, old_codebook] = code(Y, codefct)
>> [Yc, codebook, old_codebook] = code(Y, codefct, codefct_args)
>> Yc = code(Y, given_codebook)
```

**Outputs**

<code>Yc</code>	<code>N×nbits</code> encoded output classifier
<code>codebook(*)</code>	<code>nbits×nc</code> matrix representing the used encoding
<code>old_codebook(*)</code>	<code>d×nc</code> matrix representing the original encoding

**Inputs**

<code>Y</code>	<code>N×d</code> matrix representing the original classifier
<code>codefct(*)</code>	Function to generate a new codebook (e.g. <code>code_MOC</code> )
<code>codefct_args(*)</code>	Extra arguments for <code>codefct</code>
<code>given_codebook(*)</code>	<code>nbits×nc</code> matrix representing the encoding to use

- For decoding:

```
>> Yd = code(Yc, codebook, [], old_codebook)
>> Yd = code(Yc, codebook, [], old_codebook, codedist_fct)
>> Yd = code(Yc, codebook, [], old_codebook, codedist_fct, codedist_args)
```

**Outputs**

<code>Yd</code>	<code>N×nc</code> decoded output classifier
-----------------	---

**Inputs**

<code>Y</code>	<code>N×d</code> matrix representing the original classifier
<code>codebook</code>	<code>d×nc</code> matrix representing the original encoding
<code>old_codebook</code>	<code>bits×nc</code> matrix representing the encoding of the given classifier
<code>codedist_fct</code>	Function to calculate the distance between to encoded classifiers (e.g. <code>codedist_hamming</code> )
<code>codedist_args(*)</code>	Extra arguments of <code>codedist_fct</code>

**See also:**

`code_ECOC`, `code_MOC`, `code_OneVsAll`, `code_OneVsOne`, `codedist_hamming`

### A.3.11 crossvalidate

#### Purpose

*Estimate the model performance of a model with  $l$ -fold crossvalidation.*

*CAUTION!! Use this function only to obtain the value of the crossvalidation score function given the tuning parameters. Do not use this function together with `tunelssvm`, but use `crossvalidate_lssvm` instead. The latter is a faster implementation which uses previously computed results.*

#### Basic syntax

```
>> cost = crossvalidate({Xtrain,Ytrain,type,gam,sig2})
>> cost = crossvalidate(model)
```

#### Description

The data is once permuted randomly, then it is divided into  $L$  (by default 10) disjoint sets. In the  $i$ -th ( $i = 1, \dots, l$ ) iteration, the  $i$ -th set is used to estimate the performance ('validation set') of the model trained on the other  $l - 1$  sets ('training set'). Finally, the  $l$  (denoted by  $L$ ) different estimates of the performance are combined (by default by the 'mean'). The assumption is made that the input data are distributed independent and identically over the input space. As additional output, the costs in the different folds ('costs') of the data are returned:

```
>> [cost, costs] = crossvalidate(model)
```

Some commonly used criteria are:

```
>> cost = crossvalidate(model, 10, 'misclass', 'mean')
>> cost = crossvalidate(model, 10, 'mse', 'mean')
>> cost = crossvalidate(model, 10, 'mae', 'median')
```

#### Full syntax

- Using LS-SVMlab with the functional interface:

```
>> [cost, costs] = crossvalidate({X,Y,type,gam,sig2,kernel,preprocess})
>> [cost, costs] = crossvalidate({X,Y,type,gam,sig2,kernel,preprocess}, L)
>> [cost, costs] = crossvalidate({X,Y,type,gam,sig2,kernel,preprocess},...
                                L, estfct, combinefct)
```

#### Outputs

cost	Cost estimation of the $L$ -fold cross-validation
costs(*)	$L \times 1$ vector with costs estimated on the $L$ different folds

#### Inputs

X	Training input data used for defining the LS-SVM and the preprocessing
Y	Training output data used for defining the LS-SVM and the preprocessing
type	'function estimation' ('f') or 'classifier' ('c')
gam	Regularization parameter
sig2	Kernel parameter(s) (for linear kernel, use [])
kernel(*)	Kernel type (by default 'RBF_kernel')
preprocess(*)	'preprocess'(*) or 'original'
L(*)	Number of folds (by default 10)
estfct(*)	Function estimating the cost based on the residuals (by default mse)
combinefct(*)	Function combining the estimated costs on the different folds (by default mean)

- Using the object oriented interface:

```
>> [cost, costs] = crossvalidate(model)
>> [cost, costs] = crossvalidate(model, L)
>> [cost, costs] = crossvalidate(model, L, estfct)
>> [cost, costs] = crossvalidate(model, L, estfct, combinefct)
```

**Outputs**

<code>cost</code>	Cost estimation of the L-fold cross-validation
<code>costs(*)</code>	$L \times 1$ vector with costs estimated on the $L$ different folds

**Inputs**

<code>model</code>	Object oriented representation of the LS-SVM model
<code>L(*)</code>	Number of folds (by default 10)
<code>estfct(*)</code>	Function estimating the cost based on the residuals (by default <code>mse</code> )
<code>combinefct(*)</code>	Function combining the estimated costs on the different folds (by default <code>mean</code> )

**See also:**

`leaveoneout`, `gcrossvalidate`, `trainlssvm`, `simlssvm`

**A.3.12 deltablssvm****Purpose**

*Bias term correction for the LS-SVM classifier*

**Basic syntax**

```
>> model = deltablssvm(model, b_new)
```

**Description**

This function is only useful in the object oriented function interface. Set explicitly the bias term `b_new` of the LS-SVM model.

**Full syntax**

```
>> model = deltablssvm(model, b_new)
```

**Outputs**

`model`    Object oriented representation of the LS-SVM model with initial tuning parameters

**Inputs**

`model`    Object oriented representation of the LS-SVM model  
`b_new`     $m \times 1$  vector with new bias term(s) for the model

**See also:**

`roc`, `trainlssvm`, `simlssvm`, `changelssvm`

### A.3.13 denoise\_kpca

#### Purpose

*Reconstruct the data mapped on the most important principal components.*

#### Basic syntax

```
>> Xd = denoise_kpca(X, kernel, kernel_par);
```

#### Description

Denoising can be done by moving the point in input space so that its corresponding map to the feature space is optimized. This means that the data point in feature space is as close as possible with its corresponding reconstructed points by using the principal components. If the principal components are to be calculated on the same data 'X' as one wants to denoise, use the command:

```
>> Xd = denoise_kpca(X, kernel, kernel_par);
>> [Xd, lam, U] = denoise_kpca(X, kernel, kernel_par, [], etype, nb);
```

When one wants to denoise data 'Xt' other than the data used to obtain the principal components:

```
>> Xd = denoise_kpca(X, kernel, kernel_par, Xt);
>> [Xd, lam, U] = denoise_kpca(X, kernel, kernel_par, Xt, etype, nb);
```

#### Full syntax

- >> [Xd, lam, U] = denoise\_kpca(X, kernel, kernel\_par, Xt);
- >> [Xd, lam, U] = denoise\_kpca(X, kernel, kernel\_par, Xt, etype);
- >> [Xd, lam, U] = denoise\_kpca(X, kernel, kernel\_par, Xt, etype, nb);

#### Outputs

Xd	$N \times d$ ( $N_t \times d$ ) matrix with denoised data X (Xt)
lam(*)	$nb \times 1$ vector with eigenvalues of principal components
U(*)	$N \times nb$ ( $N_t \times d$ ) matrix with principal eigenvectors

#### Inputs

X	$N \times d$ matrix with data points used for finding the principal components
kernel	Kernel type (e.g. 'RBF_kernel')
kernel_par	Kernel parameter(s) (for linear kernel, use [])
Xt(*)	$N_t \times d$ matrix with noisy points (if not specified, X is denoised instead)
etype(*)	'eig'(*), 'svd', 'eigs', 'eign'
nb(*)	Number of principal components used in approximation

- >> Xd = denoise\_kpca(X, U, lam, kernel, kernel\_par, Xt);

#### Outputs

Xd	$N \times d$ ( $N_t \times d$ ) matrix with denoised data X (Xt)
----	--

#### Inputs

X	$N \times d$ matrix with data points used for finding the principal components
U	$N \times nb$ ( $N_t \times d$ ) matrix with principal eigenvectors
lam	$nb \times 1$ vector with eigenvalues of principal components
kernel	Kernel type (e.g. 'RBF_kernel')
kernel_par	Kernel parameter(s) (for linear kernel, use [])
Xt(*)	$N_t \times d$ matrix with noisy points (if not specified, X is denoised instead)

See also:

kpca, kernel\_matrix, RBF\_kernel



**A.3.14 eign****Purpose**

*Find the principal eigenvalues and eigenvectors of a matrix with Nyström's low rank approximation method*

**Basic syntax**

```
>> D      = eign(A, nb)
>> [V, D] = eign(A, nb)
```

**Description**

In the case of using this method for low rank approximation and decomposing the kernel matrix, one can call the function without explicit construction of the matrix A.

```
>> D      = eign(X, kernel, kernel_par, nb)
>> [V, D] = eign(X, kernel, kernel_par, nb)
```

**Full syntax**

We denote the size of positive definite matrix A with **a\*a**.

- Given the full matrix:

```
>> D      = eign(A,nb)
>> [V,D] = eign(A,nb)
```

**Outputs**

V(\*)     **a×nb** matrix with estimated principal eigenvectors of A  
D        **nb×1** vector with principal estimated eigenvalues of A

**Inputs**

A        **a\*a** positive definite symmetric matrix  
nb(\*)     Number of approximated principal eigenvalues/eigenvectors

- Given the function to calculate the matrix elements:

```
>> D = eign(X, kernel, kernel_par, n)
>> [V,D] = eign(X, kernel, kernel_par, n)
```

**Outputs**

V(\*)     **a×nb** matrix with estimated principal eigenvectors of A  
D        **nb×1** vector with estimated principal eigenvalues of A

**Inputs**

X        **N×d** matrix with the training data  
kernel    Kernel type (e.g. 'RBF\_kernel')  
kernel\_par Kernel parameter(s) (for linear kernel, use [])  
nb(\*)     Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

**See also:**

eig, eigs, kpca, bay\_lssvm

### A.3.15 `gcrossvalidate`

#### Purpose

*Estimate the model performance of a model with generalized crossvalidation.*

*CAUTION!! Use this function only to obtain the value of the generalized crossvalidation score function given the tuning parameters. Do not use this function together with `tunelssvm`, but use `gcrossvalidatelssvm` instead. The latter is a faster implementation which uses previously computed results.*

#### Basic syntax

```
>> cost = gcrossvalidate({Xtrain,Ytrain,type,gam,sig2})
>> cost = gcrossvalidate(model)
```

#### Description

Instead of dividing the data into  $L$  disjoint sets, one takes the complete data and the effective degrees of freedom (effective number of parameters) into account. The assumption is made that the input data are distributed independent and identically over the input space.

```
>> cost = gcrossvalidate(model)
```

Some commonly used criteria are:

```
>> cost = gcrossvalidate(model, 'misclass')
>> cost = gcrossvalidate(model, 'mse')
>> cost = gcrossvalidate(model, 'mae')
```

#### Full syntax

- Using LS-SVMlab with the functional interface:

```
>> cost = gcrossvalidate({X,Y,type,gam,sig2,kernel,preprocess})
>> cost = gcrossvalidate({X,Y,type,gam,sig2,kernel,preprocess}, estfct)
```

#### Outputs

cost	Cost estimation of the generalized cross-validation
------	---

#### Inputs

X	Training input data used for defining the LS-SVM and the preprocessing
Y	Training output data used for defining the LS-SVM and the preprocessing
type	'function estimation' ('f') or 'classifier' ('c')
gam	Regularization parameter
sig2	Kernel parameter(s) (for linear kernel, use [])
kernel(*)	Kernel type (by default 'RBF_kernel')
preprocess(*)	'preprocess'(*) or 'original'
estfct(*)	Function estimating the cost based on the residuals (by default mse)

- Using the object oriented interface:

```
>> cost = gcrossvalidate(model)
>> cost = gcrossvalidate(model, estfct)
```

**Outputs**

`cost` Cost estimation of the generalized cross-validation

**Inputs**

`model` Object oriented representation of the LS-SVM model

`estfct(*)` Function estimating the cost based on the residuals (by default `mse`)

**See also:**

`leaveoneout`, `crossvalidatelssvm`, `trainlssvm`, `simlssvm`

### A.3.16 initlssvm, changelssvm

#### Purpose

*Only for use with the object oriented model interface*

#### Description

The Matlab toolbox interface is organized in two equivalent ways. In the *functional way*, function calls need explicit input and output arguments. An advantage is their similarity with the mathematical equations.

An alternative syntax is based on the concept of a *model*, gathering all the relevant signals, parameters and algorithm choices. The model is initialized by `model=initlssvm(...)`, or will be initiated implicitly by passing the arguments of `initlssvm(...)` in one cell as the argument of the LS-SVM specific functions, e.g. for training:

```
>> model = trainlssvm({X,Y,type,gam,sig2})
...
>> model = changelssvm(model,'field','value')
```

After training, the model contains the solution of the training including the used default values. All contents of the **model** can be requested (`model.<contenttype>`) or changed (`changelssvm`) each moment. The user is advised not to change the fields of the model by `model.<field>=<value>` as the toolbox cannot guarantee consistency anymore in this way.

The different options are given in following table:

- General options representing the kind of model:

<code>type</code> :	'classifier' , 'function estimation'
<code>status</code> :	Status of this model ('trained' or 'changed' )
<code>alpha</code> :	Support values of the trained LS-SVM model
<code>b</code> :	Bias term of the trained LS-SVM model
<code>duration</code> :	Number of seconds the training lasts
<code>latent</code> :	Returning latent variables ('no' , 'yes' )
<code>x_delays</code> :	Number of delays of eXogeneous variables (by default 0 )
<code>y_delays</code> :	Number of delays of responses (by default 0 )
<code>steps</code> :	Number of steps to predict (by default 1 )
<code>gam</code> :	Regularisation parameter
<code>kernel_type</code> :	Kernel function
<code>kernel_pars</code> :	Extra parameters of the kernel function
<code>weights</code> :	Weighting function for robust regression

- Fields used to specify the used training data:

<code>x_dim</code> :	Dimension of input space
<code>y_dim</code> :	Dimension of responses
<code>nb_data</code> :	Number of training data
<code>xtrain</code> :	(preprocessed) inputs of training data
<code>ytrain</code> :	(preprocessed,coded) outputs of training data
<code>selector</code> :	Indexes of training data effectively used during training
<code>costCV</code> :	Cost of the cross-validation score function when model is tuned

- Fields with the information for pre- and post-processing (only given if appropriate):

```

preprocess: 'preprocess' or 'original'
schemed: Status of the preprocessing
          ('coded' , 'original' or 'schemed' )
pre_xscheme: Scheme used for preprocessing the input data
pre_yscheme: Scheme used for preprocessing the output data
pre_xmean: Mean of the input data
pre_xstd: Standard deviation of the input data
pre_ymean: Mean of the responses
pre_ystd: Standard deviation of the reponses

```

- The specifications of the used encoding (only given if appropriate):

```

code: Status of the coding
      ('original' , 'changed' or 'encoded')
codetype: Used function for constructing the encoding
           for multiclass classification (by default 'none')
codetype_args: Arguments of the codetype function
codedist_fct: Function used to calculate to which class a
              coded result belongs
codedist_args: Arguments of the codedist function
codebook2: Codebook of the new coding
codebook1: Codebook of the original coding

```

### Full syntax

- `>> model = initlssvm(X, Y, type, gam, sig2, kernel, preprocess)`

#### Outputs

`model`                      Object oriented representation of the LS-SVM model

#### Inputs

`X`                           $N \times d$  matrix with the inputs of the training data  
`Y`                           $N \times 1$  vector with the outputs of the training data  
`type`                      'function estimation' ('f') or 'classifier' ('c')  
`gam`                        Regularization parameter  
`sig2`                      Kernel parameter(s) (for linear kernel, use [])  
`kernel(*)`                Kernel type (by default 'RBF\_kernel')  
`preprocess(*)`           'preprocess'(\*) or 'original'

- `>> model = changelssvm(model, field, value)`

#### Outputs

`model(*)`                  Obtained object oriented representation of the LS-SVM model

#### Inputs

`model`                      Original object oriented representation of the LS-SVM model  
`field`                      Field of the model that one wants to change (e.g. 'preprocess')  
`value`                      New value of the field of the model that one wants to change

See also:

`trainlssvm`, `initlssvm`, `simlssvm`, `plotlssvm`.

### A.3.17 kentropy

#### Purpose

*Quadratic Renyi Entropy for a kernel based estimator*

#### Basic syntax

Given the eigenvectors and the eigenvalues of the kernel matrix, the entropy is computed by

```
>> H = kentropy(X, U, lam)
```

The eigenvalue decomposition can also be computed (or approximated) implicitly:

```
>> H = kentropy(X, kernel, sig2)
```

#### Full syntax

- >> H = kentropy(X, kernel, kernel\_par)
- >> H = kentropy(X, kernel, kernel\_par, etype)
- >> H = kentropy(X, kernel, kernel\_par, etype, nb)

#### Outputs

H                      Quadratic Renyi entropy of the kernel matrix

#### Inputs

X                      N×d matrix with the training data  
 kernel                Kernel type (e.g. 'RBF\_kernel')  
 kernel\_par          Kernel parameter(s) (for linear kernel, use [])  
 etype(\*)            'eig'(\*), 'eigs', 'eign'  
 nb(\*)                Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation

- >> H = kentropy(X, U, lam)

#### Outputs

H                      Quadratic Renyi entropy of the kernel matrix

#### Inputs

X                      N×d matrix with the training data  
 U                      N×nb matrix with principal eigenvectors  
 lam                   nb×1 vector with eigenvalues of principal components

See also:

kernel\_matrix, demo\_fixedsized, RBF\_kernel

**A.3.18 kernel\_matrix****Purpose**

*Construct the positive (semi-) definite and symmetric kernel matrix*

**Basic Syntax**

```
>> Omega = kernel_matrix(X, kernel_fct, sig2)
```

**Description**

This matrix should be positive definite if the kernel function satisfies the Mercer condition. Construct the kernel values for all test data points in the rows of **Xt**, relative to the points of **X**.

```
>> Omega_Xt = kernel_matrix(X, kernel_fct, sig2, Xt)
```

**Full syntax**

```
>> Omega = kernel_matrix(X, kernel_fct, sig2)
>> Omega = kernel_matrix(X, kernel_fct, sig2, Xt)
```

**Outputs**

**Omega**      $N \times N$  ( $N \times N_t$ ) kernel matrix

**Inputs**

**X**              $N \times d$  matrix with the inputs of the training data  
**kernel**       Kernel type (by default 'RBF\_kernel')  
**sig2**          Kernel parameter(s) (for linear kernel, use [])  
**Xt(\*)**          $N_t \times d$  matrix with the inputs of the test data

**See also:**

RBF\_kernel, lin\_kernel, kpca, trainlssvm

### A.3.19 kpca

#### Purpose

*Kernel Principal Component Analysis (KPCA)*

#### Basic syntax

```
>> [eigval, eigvec] = kpca(X, kernel_fct, sig2)
>> [eigval, eigvec, scores] = kpca(X, kernel_fct, sig2, Xt)
```

#### Description

Compute the `nb` largest eigenvalues and the corresponding rescaled eigenvectors corresponding with the principal components in the feature space of the centered kernel matrix. To calculate the eigenvalue decomposition of this  $N \times N$  matrix, Matlab's `eig` is called by default. The decomposition can also be approximated by Matlab (`'eigs'`) or by Nyström's method (`'eign'`) using `nb` components. In some cases one wants to disable (`'original'`) the rescaling of the principal components in feature space to unit length.

The scores of a test set `Xt` on the principal components is computed by the call:

```
>> [eigval, eigvec, scores] = kpca(X, kernel_fct, sig2, Xt)
```

#### Full syntax

```
>> [eigval, eigvec, empty, omega] = kpca(X, kernel_fct, sig2)
>> [eigval, eigvec, empty, omega] = kpca(X, kernel_fct, sig2, [], etype)
>> [eigval, eigvec, empty, omega] = kpca(X, kernel_fct, sig2, [], etype, nb)
>> [eigval, eigvec, empty, omega] = kpca(X, kernel_fct, sig2, [], etype, nb, rescaling)
>> [eigval, eigvec, scores, omega] = kpca(X, kernel_fct, sig2, Xt)
>> [eigval, eigvec, scores, omega] = kpca(X, kernel_fct, sig2, Xt, etype)
>> [eigval, eigvec, scores, omega] = kpca(X, kernel_fct, sig2, Xt, etype, nb)
>> [eigval, eigvec, scores, omega] = kpca(X, kernel_fct, sig2, Xt, etype, nb, rescaling)
>> [eigval, eigvec, scores, omega, recErrors] = kpca(X, kernel_fct, sig2, Xt, etype)
>> [eigval, eigvec, scores, omega, recErrors] = kpca(X, kernel_fct, sig2, Xt, ...
etype, nb)

>> [eigval, eigvec, scores, omega, recErrors] = kpca(X, kernel_fct, sig2, Xt, ...
etype, nb, rescaling)

>> [eigval, eigvec, scores, omega, recErrors, optOut] = kpca(X, kernel_fct, ...
sig2, Xt, etype)

>> [eigval, eigvec, scores, omega, recErrors, optOut] = kpca(X, kernel_fct, sig2, Xt, ...
etype, nb)

>> [eigval, eigvec, scores, omega, recErrors, optOut] = kpca(X, kernel_fct, sig2, Xt, ...
etype, nb, rescaling)
```



**Outputs**

<code>eigval</code>	$N(\text{nb}) \times 1$ vector with eigenvalues values
<code>eigvec</code>	$N \times N$ ( $N \times \text{nb}$ ) matrix with the principal directions
<code>scores(*)</code>	$N_t \times \text{nb}$ matrix of the scores of test data (or <code>[]</code> )
<code>omega(*)</code>	$N \times N$ centered kernel matrix
<code>recErrors(*)</code>	$N_t \times 1$ vector with the reconstruction errors of test data
<code>optOut(*)</code>	$1 \times 2$ cell array with the centered test kernel matrix in <code>optOut{1}</code> and the squared norms of the test points in the feature space in <code>optOut{2}</code>

**Inputs**

<code>X</code>	$N \times d$ matrix with the inputs of the training data
<code>kernel</code>	Kernel type (e.g. <code>'RBF_kernel'</code> )
<code>sig2</code>	Kernel parameter(s) (for linear kernel, use <code>[]</code> )
<code>Xt(*)</code>	$N_t \times d$ matrix with the inputs of the test data (or <code>[]</code> )
<code>etype(*)</code>	<code>'svd'</code> , <code>'eig'(*)</code> , <code>'eigs'</code> , <code>'eign'</code>
<code>nb(*)</code>	Number of eigenvalues/eigenvectors used in the eigenvalue decomposition approximation
<code>rescaling(*)</code>	<code>'original size' ('o')</code> or <code>'rescaling'(*) ('r')</code>

**See also:**

bay\_lssvm, bay\_optimize, eign

### A.3.20 latentlssvm

#### Purpose

*Calculate the latent variables of the LS-SVM classifier at the given test data*

#### Basic syntax

```
>> Zt = latentlssvm({X,Y,'classifier',gam,sig2,kernel}, {alpha,b}, Xt)
>> Zt = latentlssvm({X,Y,'classifier',gam,sig2,kernel}, Xt)
>> [Zt, model] = latentlssvm(model, Xt)
```

#### Description

The latent variables of a binary classifier are the continuous simulated values of the test or training data which are used to make the final classifications. The classification of a test point depends on whether the latent value exceeds the model's threshold (b). If appropriate, the model is trained by the standard procedure (`trainlssvm`) first.

#### Full syntax

- Using the functional interface:

```
>> Zt = latentlssvm({X,Y,'classifier',gam,sig2,kernel}, {alpha,b}, Xt)
>> Zt = latentlssvm({X,Y,type,gam,sig2,kernel,preprocess}, Xt)
```

#### Outputs

**Zt**  $N_t \times m$  matrix with predicted latent simulated outputs

#### Inputs

**X**  $N \times d$  matrix with the inputs of the training data  
**Y**  $N \times m$  vector with the outputs of the training data  
**type** 'classifier' ('c')  
**gam** Regularization parameter  
**sig2** Kernel parameter(s) (for linear kernel, use [])  
**kernel(\*)** Kernel type (by default 'RBF\_kernel')  
**preprocess(\*)** 'preprocess'(\*) or 'original'  
**alpha(\*)**  $N \times 1$  matrix with the support values  
**b(\*)** the bias terms  
**Xt**  $N_t \times d$  matrix with the inputs of the test data

- Using the object oriented interface:

```
>> [Zt, model] = latentlssvm(model, Xt)
```

#### Outputs

**Zt**  $N_t \times m$  matrix with continuous latent simulated outputs  
**model(\*)** Trained object oriented representation of the LS-SVM model

#### Inputs

**model** Object oriented representation of the LS-SVM model  
**Xt**  $N_t \times d$  matrix with the inputs of the test data

See also:

`trainlssvm`, `simlssvm`

**A.3.21 leaveoneout****Purpose**

*Estimate the performance of a trained model with leave-one-out crossvalidation.*

*CAUTION!! Use this function only to obtain the value of the leave-one-out crossvalidation score function given the tuning parameters. Do not use this function together with `tunelssvm`, but use `leaveoneoutlssvm` instead. The latter is a faster implementation based on one full matrix inverse.*

**Basic syntax**

```
>> leaveoneout({X,Y,type,gam,sig2})
>> leaveoneout(model)
```

**Description**

In each iteration, one leaves out one point, and fits a model on the other data points. The performance of the model is estimated based on the point left out. This procedure is repeated for each data point. Finally, all the different estimates of the performance are combined (default by computing the mean). The assumption is made that the input data is distributed independent and identically over the input space.

**Full syntax**

- Using the functional interface for the LS-SVMs:

```
>> cost = leaveoneout({X,Y,type,gam,sig2,kernel,preprocess})
>> cost = leaveoneout({X,Y,type,gam,sig2,kernel,preprocess}, estfct, combinefct)
```

**Outputs**

<code>cost</code>	Cost estimated by leave-one-out crossvalidation
-------------------	---

**Inputs**

<code>X</code>	Training input data used for defining the LS-SVM and the preprocessing
<code>Y</code>	Training output data used for defining the LS-SVM and the preprocessing
<code>type</code>	'function estimation' ('f') or 'classifier' ('c')
<code>gam</code>	Regularization parameter
<code>sig2</code>	Kernel parameter(s) (for linear kernel, use [])
<code>kernel(*)</code>	Kernel type (by default 'RBF_kernel')
<code>preprocess(*)</code>	'preprocess'(*) or 'original'
<code>estfct(*)</code>	Function estimating the cost based on the residuals (by default <code>mse</code> )
<code>combinefct(*)</code>	Function combining the estimated costs on the different folds (by default <code>mean</code> )

- Using the object oriented interface for the LS-SVMs:

```
>> cost = leaveoneout(model)
>> cost = leaveoneout(model, estfct)
>> cost = leaveoneout(model, estfct, combinefct)
```

**Outputs**

`cost` Cost estimated by leave-one-out crossvalidation

**Inputs**

`model` Object oriented representation of the model

`estfct(*)` Function estimating the cost based on the residuals (by default `mse`)

`combinefct(*)` Function combining the estimated costs on the different folds (by default `mean`)

**See also:**

`crossvalidate`, `trainlssvm`, `simlssvm`

**A.3.22** `lin_kernel`, `MLP_kernel`, `poly_kernel`, `RBF_kernel`**Purpose**

*Kernel implementations used with the Matlab training and simulation procedure*

**Description**`lin_kernel`

Linear kernel:

$$K(x_i, x_j) = x_i^T x_j$$

`poly_kernel`

Polynomial kernel:

$$K(x_i, x_j) = (x_i^T x_j + t)^d, \quad t \geq 0$$

with  $t$  the intercept and  $d$  the degree of the polynomial.

`RBF_kernel`

Radial Basis Function kernel:

$$K(x_i, x_j) = e^{-\frac{\|x_i - x_j\|^2}{\sigma^2}}$$

with  $\sigma^2$  the variance of the Gaussian kernel.

`MLP_kernel`

Multilayer perceptron kernel:

$$K(x_i, x_j) = \tanh(s x_i^T x_j + \theta)$$

with  $\theta$  and  $s$  tuning parameters.

**Full syntax**

```
>> v = RBF_kernel(x1, X2, sig2)
```

**Outputs**

`v`                       $N \times 1$  vector with kernel values

**Calls**

`RBF_kernel`    or `lin_kernel`, `MLP_kernel`, `poly_kernel`,...

**Inputs**

`x1`                       $1 \times d$  matrix with a data point

`X2`                       $N \times d$  matrix with data points

`sig2`                    Kernel parameters

**See also:**

`kernel_matrix`, `kpca`, `trainlssvm`

**A.3.23** `linf`, `mae`, `medae`, `misclass`, `mse`**Purpose***Cost measures of residuals***Description**

A variety of global distance measures can be defined:

- `mae`:  $L_1$   $C_{L_1}(e) = \frac{\sum_{i=1}^N |e_i|}{N}$
- `medae`:  $L_1$   $C_{L_1}^{median}(e) = \text{median}_{i=1}^N |e_i|$
- `linf`:  $L_\infty$   $C_{L_\infty}(e) = \sup_i |e_i|$
- `misclass`:  $L_0$   $C_{L_0}(e) = \frac{\sum_{i=1}^N |y_i \neq \hat{y}_i|}{N}$
- `mse`:  $L_2$   $C_{L_2}(e) = \frac{\sum_{i=1}^N e_i^2}{N}$

**Full syntax**

- `>> C = mse(e)`

**Outputs**`C` Estimated cost of the residuals**Calls**`mse` `mae`, `medae`, `linf` or `mse`**Inputs**`e`  $N \times d$  matrix with residuals

- `>> [C, which] = trimmedmse(e, beta, norm)`

**Outputs**`C` Estimated cost of the residuals`which(*)`  $N \times d$  matrix with indexes of the used residuals**Inputs**`e`  $N \times d$  matrix with residuals`beta(*)` Trimming factor (by default 0.15)`norm(*)` Function implementing norm (by default `squared norm`)

- `>> [rate, n, which] = misclass(Y, Yh)`

**Outputs**`rate` Rate of misclassification (between 0 (none misclassified) and 1 (all misclassified))`n(*)` Number of misclassified data points`which(*)` Indexes of misclassified points**Inputs**`Y`  $N \times d$  matrix with true class labels`Yh`  $N \times d$  matrix with estimated class labels**See also:**`crossvalidate`, `leaveoneout`, `rcrossvalidate`

**A.3.24 lssvm****Purpose**

*Construct an LS-SVM model with one command line and visualize results if possible*

**Basic syntax**

```
>> yp = lssvm(X,Y,type)
>> yp = lssvm(X,Y,type,kernel)
```

**Description**

`type` can be `'classifier'` or `'function estimation'` (these strings can be abbreviated into `'c'` or `'f'`, respectively). `X` and `Y` are matrices holding the training input and training output. The  $i$ -th data point is represented by the  $i$ -th row `X(i,:)` and `Y(i,:)`. The tuning parameters are automatically tuned via leave-one-out cross-validation or 10-fold cross-validation depending on the size of the data set. Leave-one-out cross-validation is used when the size is less or equal than 300 points. The loss functions for cross-validation are `mse` for regression and `misclass` for classification. If possible, the results will be visualized using `plotlssvm`. By default the Gaussian RBF kernel is used. Other kernels can be used, for example

```
>> Yp = lssvm(X,Y,type,'lin_kernel')
>> Yp = lssvm(X,Y,type,'poly_kernel')
```

When using the polynomial kernel there is no need to specify the degree of the polynomial, the software will automatically tune it to obtain best performance on the cross-validation or leave-one-out score functions.

```
>> Yp = lssvm(X,Y,type,'RBF_kernel')
>> Yp = lssvm(X,Y,type,'lin_kernel')
>> Yp = lssvm(X,Y,type,'poly_kernel')
```

**Full syntax**

```
>> [Yp,alpha,b,gam,sig2,model] = lssvm(X,Y,type)
>> [Yp,alpha,b,gam,sig2,model] = lssvm(X,Y,type,kernel)
```

**Inputs**

<code>X</code>	$N \times d$ matrix with the inputs of the training data
<code>Y</code>	$N \times 1$ vector with the outputs of the training data
<code>type</code>	<code>'function estimation'</code> ( <code>'f'</code> ) or <code>'classifier'</code> ( <code>'c'</code> )
<code>kernel(*)</code>	Kernel type (by default <code>'RBF_kernel'</code> )

**Outputs**

<code>Yp</code>	$N \times m$ matrix with output of the training data
<code>alpha(*)</code>	$N \times m$ matrix with support values of the LS-SVM
<code>b(*)</code>	$1 \times m$ vector with bias term(s) of the LS-SVM
<code>gam(*)</code>	Regularization parameter (determined by cross-validation)
<code>sig2(*)</code>	Squared bandwidth (determined by cross-validation), for linear kernel <code>sig2=0</code>
<code>model(*)</code>	Trained object oriented representation of the LS-SVM model

**See also:**

`trainlssvm`, `simlssvm`, `crossvalidate`, `leaveoneout`, `plotlssvm`.

### A.3.25 plotlssvm

#### Purpose

*Plot the LS-SVM results in the environment of the training data*

#### Basic syntax

```
>> plotlssvm({X,Y,type,gam, sig2, kernel})
>> plotlssvm({X,Y,type,gam, sig2, kernel}, {alpha,b})
>> model = plotlssvm(model)
```

#### Description

The first argument specifies the LS-SVM. The latter specifies the results of the training if already known. Otherwise, the training algorithm is first called. One can specify the precision of the plot by specifying the **grain** of the grid. By default this value is 50. The dimensions (**seldims**) of the input data to display can be selected as an optional argument in case of higher dimensional inputs ( $> 2$ ). A grid will be taken over this dimension, while the other inputs remain constant (0).

#### Full syntax

- Using the functional interface:

```
>> plotlssvm({X,Y,type,gam,sig2,kernel,preprocess}, {alpha,b})
>> plotlssvm({X,Y,type,gam,sig2,kernel,preprocess}, {alpha,b}, grain)
>> plotlssvm({X,Y,type,gam,sig2,kernel,preprocess}, {alpha,b}, grain, seldims)
>> plotlssvm({X,Y,type,gam,sig2,kernel,preprocess})
>> plotlssvm({X,Y,type,gam,sig2,kernel,preprocess}, [], grain)
>> plotlssvm({X,Y,type,gam,sig2,kernel,preprocess}, [], grain, seldims)
```

#### Inputs

<b>X</b>	$N \times d$ matrix with the inputs of the training data
<b>Y</b>	$N \times 1$ vector with the outputs of the training data
<b>type</b>	'function estimation' ('f') or 'classifier' ('c')
<b>gam</b>	Regularization parameter
<b>sig2</b>	Kernel parameter(s) (for linear kernel, use [])
<b>kernel(*)</b>	Kernel type (by default 'RBF_kernel')
<b>preprocess(*)</b>	'preprocess'(*) or 'original'
<b>alpha(*)</b>	Support values obtained from training
<b>b(*)</b>	Bias term obtained from training
<b>grain(*)</b>	The grain of the grid evaluated to compose the surface (by default 50)
<b>seldims(*)</b>	The principal inputs one wants to span a grid (by default [1 2])

- Using the object oriented interface:

```
>> model = plotlssvm(model)
>> model = plotlssvm(model, [], grain)
>> model = plotlssvm(model, [], grain, seldims)
```

#### Outputs

<b>model(*)</b>	Trained object oriented representation of the LS-SVM model
-----------------	--

#### Inputs

<b>model</b>	Object oriented representation of the LS-SVM model
<b>grain(*)</b>	The grain of the grid evaluated to compose the surface (by default 50)
<b>seldims(*)</b>	The principal inputs one wants to span a grid (by default [1 2])

**See also:**

trainlssvm, simlssvm.



**A.3.26 predict****Purpose**

*Iterative prediction of a trained LS-SVM NARX model (in recurrent mode)*

**Description**

```
>> Yp = predict({Xw,Yw,type,gam,sig2}, Xt, nb)
>> Yp = predict(model, Xt, nb)
```

**Description**

The model needs to be trained using **Xw**, **Yw** which is the result of **windowize** or **windowizeNARX**. The number of time lags for the model is determined by the dimension of the input, or if not appropriate, by the number of given starting values.

By default, the model is evaluated on the past points using **simlssvm**. However, if one wants to use this procedure for other models, this default can be overwritten by your favorite training function. This function (denoted by **simfct**) has to follow the following syntax:

```
>> simfct(model,inputs,arguments)
```

thus:

```
>> Yp = predict(model, Xt, nb, simfct)
>> Yp = predict(model, Xt, nb, simfct, arguments)
```

**Full syntax**

- Using the functional interface for the LS-SVMs:

```
>> Yp = predict({Xw,Yw,type,gam,sig2,kernel,preprocess}, Xt)
>> Yp = predict({Xw,Yw,type,gam,sig2,kernel,preprocess}, Xt, nb)
```

**Outputs**

**Yp**                       $\text{nb} \times 1$  matrix with the predictions

**Inputs**

**Xw**                       $N \times d$  matrix with the inputs of the training data  
**Yw**                       $N \times 1$  matrix with the outputs of the training data  
**type**                    'function estimation' ('f') or 'classifier' ('c')  
**gam**                     Regularization parameter  
**sig2**                    Kernel parameter(s) (for linear kernel, use [])  
**kernel(\*)**               Kernel type (by default 'RBF\_kernel')  
**preprocess(\*)**           'preprocess' or 'original' (by default)  
**Xt**                       $\text{nb} \times 1$  matrix of the starting points for the prediction  
**nb(\*)**                    Number of outputs to predict

- Using the object oriented interface with LS-SVMs:

```
>> Yp = predict(model, Xt)
>> Yp = predict(model, Xt, nb)
```

**Outputs**

**Yp**                       $\text{nb} \times 1$  matrix with the predictions

**Inputs**

**model**                  Object oriented representation of the LS-SVM model  
**Xt**                       $\text{nb} \times 1$  matrix of the starting points for the prediction  
**nb(\*)**                    Number of outputs to predict

- Using another model:

```
>> Yp = predict(model, Xt, nb, simfct, arguments)
```

**Outputs**

Yp                    nb×1 matrix with the predictions

**Inputs**

model	Object oriented representation of the LS-SVM model
Xt	nb×1 matrix of the starting points for the prediction
nb	Number of outputs to predict
simfct	Function used to evaluate a test point
arguments(*)	Cell with the extra arguments passed to <code>simfct</code>

**See also:**

windowize, trainlssvm, simlssvm.

**A.3.27 predlssvm****Purpose**

*Construction of bias corrected  $100(1 - \alpha)\%$  pointwise or simultaneous prediction intervals*

**Description**

```
>> pi = predlssvm({X,Y,type,gam,sig2,kernel,preprocess}, Xt, alpha, conftype)
>> pi = predlssvm(model,Xt, alpha, conftype)
```

**Description**

This function calculates bias corrected  $100(1 - \alpha)\%$  pointwise or simultaneous prediction intervals. The procedure support homoscedastic data sets as well heteroscedastic data sets. The construction of the prediction intervals are based on the central limit theorem for linear smoothers combined with bias correction and variance estimation.

**Full syntax**

- Using the functional interface:

```
>> pi = predlssvm({X,Y,type,gam,kernel_par,kernel,preprocess}, Xt)
>> pi = predlssvm({X,Y,type,gam,kernel_par,kernel,preprocess}, Xt, alpha)
>> pi = predlssvm({X,Y,type,gam,kernel_par,kernel,preprocess}, Xt, alpha, conftype)
```

**Outputs**

pi  $N \times 2$  matrix containing the lower and upper prediction intervals

**Inputs**

X	Training input data used for defining the LS-SVM and preprocessing
Y	Training output data used for defining the LS-SVM and preprocessing
type	'function estimation' ('f') or 'classifier' ('c')
gam	Regularization parameter
sig2	Kernel parameter(s) (for linear kernel, use [])
kernel(*)	Kernel type (by default 'RBF_kernel')
preprocess(*)	'preprocess'(*) or 'original'
Xt	Test points where prediction intervals are calculated
alpha(*)	Significance level (by default 5%)
conftype(*)	Type of prediction interval 'pointwise' or 'simultaneous' (by default 'simultaneous')

- Using the object oriented interface:

```
>> pi = predlssvm(model)
>> pi = predlssvm(model, Xt, alpha)
>> pi = predlssvm(model, Xt, alpha, conftype)
```

**Outputs**

pi  $N \times 2$  matrix containing the lower and upper prediction intervals

**Inputs**

model	Object oriented representation of the LS-SVM model
alpha(*)	Significance level (by default 5%)
conftype(*)	Type of prediction interval 'pointwise' or 'simultaneous' (by default 'simultaneous')

**See also:**

trainlssvm, simlssvm, cilssvm

### A.3.28 preimage\_rbf

#### Purpose

*Reconstruction or denoising after kernel PCA with RBF kernels, i.e. to find the approximate pre-image (in the input space) of the corresponding feature space expansions.*

#### Basic syntax

```
>> Xdtr = preimage_rbf(Xtr,sig2,U) % denoising on training data;
```

#### Description

This method uses a fixed-point iteration scheme to obtain approximate pre-images for RBF kernels only. Denoising a test set `Xnoisy` can be done using:

```
>> Xd = preimage_rbf(Xtr,sig2,U,Xnoisy,'d');
```

and for reconstructing feature space expansions:

```
>> Xr = preimage_rbf(Xtr,sig2,U,projections,'r');
```

#### Full syntax

- >> `Ximg = preimage_rbf(Xtr,sig2,U,B,type);`
- >> `Ximg = preimage_rbf(Xtr,sig2,U,B,type,npes);`
- >> `Ximg = preimage_rbf(Xtr,sig2,U,B,type,npes,maxIts);`

#### Outputs

`Ximg`  $N \times d$  ( $N_t \times d$ ) matrix with reconstructed or denoised data

#### Inputs

`Xtr`  $N \times d$  matrix with training data points used for finding the principal components

`sig2` parameter of the RBF kernel

`U`  $N \times npes$  matrix of principal eigenvectors

`B` for reconstruction `B` are the projections, for denoising `B` is the  $N_t \times d$  matrix of noisy data. If `B` is not specified, then `Xtr` is denoised instead

`type` 'reconstruct' or 'denoise'

`npes` number of PCs used for approximation

`maxIts` maximum iterations allowed, 1000 by default.

#### See also:

`denoise_kpca`, `kpca`, `kernel_matrix`, `rbf_kernel`

**A.3.29** `prelssvm`, `postlssvm`**Purpose***Pre- and postprocessing of the LS-SVM***Description**

These functions should only be called by `trainlssvm` or by `simlssvm`. At first the preprocessing assigns a label to each input and output component (`a` for categorical, `b` for binary variables or `c` for continuous). According to this label each dimension is rescaled:

- continuous: zero mean and unit variance
- categorical: no preprocessing
- binary: labels  $-1$  and  $+1$

**Full syntax**

Using the object oriented interface:

- Preprocessing:

```
>> model = prelssvm(model)
>> Xp = prelssvm(model, Xt)
>> [empty, Yp] = prelssvm(model, [], Yt)
>> [Xp, Yp] = prelssvm(model, Xt, Yt)
```

**Outputs**

<code>model</code>	Preprocessed object oriented representation of the LS-SVM model
<code>Xp</code>	$N_t \times d$ matrix with the preprocessed inputs of the test data
<code>Yp</code>	$N_t \times d$ matrix with the preprocessed outputs of the test data

**Inputs**

<code>model</code>	Object oriented representation of the LS-SVM model
<code>Xt</code>	$N_t \times d$ matrix with the inputs of the test data to preprocess
<code>Yt</code>	$N_t \times d$ matrix with the outputs of the test data to preprocess

- Postprocessing:

```
>> model = postlssvm(model)
>> Xt = postlssvm(model, Xp)
>> [empty, Yt] = postlssvm(model, [], Yp)
>> [Xt, Yt] = postlssvm(model, Xp, Yp)
```

**Outputs**

<code>model</code>	Postprocessed object oriented representation of the LS-SVM model
<code>Xt</code>	$N_t \times d$ matrix with the postprocessed inputs of the test data
<code>Yt</code>	$N_t \times d$ matrix with the postprocessed outputs of the test data

**Inputs**

<code>model</code>	Object oriented representation of the LS-SVM model
<code>Xp</code>	$N_t \times d$ matrix with the inputs of the test data to postprocess
<code>Yp</code>	$N_t \times d$ matrix with the outputs of the test data to postprocess

### A.3.30 rcrossvalidate

#### Purpose

*Estimate the model performance with robust L-fold crossvalidation (only regression).*

*CAUTION!! Use this function only to obtain the value of the robust L-fold crossvalidation score function given the tuning parameters. Do not use this function together with `tunelssvm`, but use `rcrossvalidate` instead.*

#### Basic syntax

```
>> cost = rcrossvalidate(model)
>> cost = rcrossvalidate({X,Y,'function',gam,sig2})
```

#### Description

Robustness in the  $l$ -fold crossvalidation score function is obtained by iteratively reweighting schemes. This routine is ONLY valid for regression!!

#### Full syntax

- Using LS-SVMlab with the functional interface:

```
>> [cost, costs] = rcrossvalidate({X,Y,type,gam,sig2,kernel,preprocess})
>> [cost, costs] = rcrossvalidate({X,Y,type,gam,sig2,kernel,preprocess}, L)
>> [cost, costs] = rcrossvalidate({X,Y,type,gam,sig2,kernel,preprocess}, L,...
                                wfun, estfct)
>> [cost, costs] = rcrossvalidate({X,Y,type,gam,sig2,kernel,preprocess}, L,...
                                wfun, estfct, combinefct)
```

#### Outputs

<code>cost</code>	Cost estimation of the robust L-fold cross-validation
<code>costs(*)</code>	$L \times 1$ vector with costs estimated on the $L$ different folds

#### Inputs

<code>X</code>	Training input data used for defining the LS-SVM and the preprocessing
<code>Y</code>	Training output data used for defining the LS-SVM and the preprocessing
<code>type</code>	'function estimation' ('f') or 'classifier' ('c')
<code>gam</code>	Regularization parameter
<code>sig2</code>	Kernel parameter(s) (for linear kernel, use [])
<code>kernel(*)</code>	Kernel type (by default 'RBF_kernel')
<code>preprocess(*)</code>	'preprocess'(*) or 'original'
<code>L(*)</code>	Number of folds (by default 10)
<code>wfun(*)</code>	weighting scheme (by default: <code>whuber</code> )
<code>estfct(*)</code>	Function estimating the cost based on the residuals (by default <code>mse</code> )
<code>combinefct(*)</code>	Function combining the estimated costs on the different folds (by default <code>mean</code> )

- Using the object oriented interface:

```
>> [cost, costs] = rcrossvalidate(model)
>> [cost, costs] = rcrossvalidate(model, L)
>> [cost, costs] = rcrossvalidate(model, L, wfun)
>> [cost, costs] = rcrossvalidate(model, L, wfun, estfct)
```

```
>> [cost, costs] = rcrossvalidate(model, L, wfun, ...
                                estfct, combinefct)
```

**Outputs**

<code>cost</code>	Cost estimation of the robust L-fold cross-validation
<code>costs(*)</code>	$L \times 1$ vector with costs estimated on the $L$ different folds
<code>ec(*)</code>	$N \times 1$ vector with residuals of all data

**Inputs**

<code>model</code>	Object oriented representation of the LS-SVM model
<code>L(*)</code>	Number of folds (by default 10)
<code>wfun(*)</code>	weighting scheme (by default: <code>whuber</code> )
<code>estfct(*)</code>	Function estimating the cost based on the residuals (by default <code>mse</code> )
<code>combinefct(*)</code>	Function combining the estimated costs on the different folds (by default <code>mean</code> )

**See also:**

`mae`, `weightingscheme`, `crossvalidate`, `trainlssvm`, `robustlssvm`

### A.3.31 `ridgeregress`

#### Purpose

*Linear ridge regression*

#### Basic syntax

```
>> [w, b] = ridgeregress(X, Y, gam)
>> [w, b, Yt] = ridgeregress(X, Y, gam, Xt)
```

#### Description

Ordinary least squares on training errors together with minimization of a regularization parameter (`gam`).

#### Full syntax

```
>> [w, b] = ridgeregress(X, Y, gam)
>> [w, b, Yt] = ridgeregress(X, Y, gam, Xt)
```

#### Outputs

`w`  $d \times 1$  vector with the regression coefficients  
`b` bias term  
`Yt(*)`  $Nt \times 1$  vector with predicted outputs of test data

#### Inputs

`X`  $N \times d$  matrix with the inputs of the training data  
`Y`  $N \times 1$  vector with the outputs of the training data  
`gam` Regularization parameter  
`Xt(*)`  $Nt \times d$  matrix with the inputs of the test data

#### See also:

`bay_rr`, `bay_lssvm`



**A.3.32 robustlssvm****Purpose**

*Robust training in the case of non-Gaussian noise or outliers*

**Basic syntax**

```
>> [alpha, b] = robustlssvm({X,Y,type,gam,sig2,kernel})
>> model      = robustlssvm(model)
```

Robustness towards outliers can be achieved by reducing the influence of support values corresponding to large errors. One should first use the function `tunelssvm` so all the necessary parameters are optimally tuned before calling this routine.

**Full syntax**

- Using the functional interface:

```
>> [alpha, b] = robustlssvm({X,Y,type,gam,sig2})
>> [alpha, b] = robustlssvm({X,Y,type,gam,sig2,kernel})
>> [alpha, b] = robustlssvm({X,Y,type,gam,sig2,kernel, preprocess})
>> [alpha, b] = robustlssvm({X,Y,type,gam,sig2,kernel, preprocess}, {alpha,b})
```

**Outputs**

alpha	N×1 matrix with support values of the robust LS-SVM
b	1×1 vector with bias term(s) of the robust LS-SVM

**Inputs**

X	N×d matrix with the inputs of the training data
Y	N×1 vector with the outputs of the training data
type	'function estimation' ('f') or 'classifier' ('c')
gam	Regularization parameter
sig2	Kernel parameter(s) (for linear kernel, use [])
kernel(*)	Kernel type (by default 'RBF_kernel')
preprocess(*)	'preprocess'(*) or 'original'
alpha(*)	Support values obtained from training
b(*)	Bias term obtained from training

- Using the object oriented interface:

```
>> model = robustlssvm(model)
```

**Outputs**

model	Robustly trained object oriented representation of the LS-SVM model
-------	---

**Inputs**

model	Object oriented representation of the LS-SVM model
-------	--

See also:

`trainlssvm`, `tunelssvm`, `rcrossvalidate`

### A.3.33 roc

#### Purpose

*Receiver Operating Characteristic (ROC) curve of a binary classifier*

#### Basic syntax

```
>> [area, se, thresholds, oneMinusSpec, sens, TN, TP, FN, FP] = roc(Zt, Y)
```

#### Description

The ROC curve [11] shows the separation abilities of a binary classifier: by setting different possible classifier thresholds, the data set is tested on misclassifications [16]. As a result, a plot is shown where the various outcomes are described. If the plot has an area under the curve of 1 on test data, a perfectly separating classifier is found (on that particular dataset), if the area equals 0.5, the classifier has no discriminative power at all. In general, this function can be called with the latent variables **Zt** and the corresponding class labels **Yclass**

```
>> Zt      = [-.7      Yclass = [-1
              .3        -1
              1.5        1
              ...        ..
              -.2]       1]
>> roc(Zt, Yclass)
```

For use in LS-SVMlab, a shorthand notation allows making the ROC curve on the training data. Implicit training and simulation of the latent values simplifies the call.

```
>> roc({X,Y,'classifier',gam,sig2,kernel})
>> roc(model)
```

#### Full syntax

- Standard call (LS-SVMlab independent):

```
>> [area, se, thresholds, oneMinusSpec, sens, TN, TP, FN, FP] = roc(Zt, Y)
>> [area, se, thresholds, oneMinusSpec, sens, TN, TP, FN, FP] = roc(Zt, Y, figure)
```

#### Outputs

<code>area(*)</code>	Area under the ROC curve
<code>se(*)</code>	Standard deviation of the residuals
<code>thresholds(*)</code>	$N \times 1$ different thresholds value
<code>oneMinusSpec(*)</code>	1-Specificity of each threshold value
<code>sens(*)</code>	Sensitivity for each threshold value
<code>TN(*)</code>	Number of true negative predictions
<code>TP(*)</code>	Number of true positive predictions
<code>FN(*)</code>	Number of false negative predictions
<code>FP(*)</code>	Number of false positive predictions

#### Inputs

<code>Zt</code>	$N \times 1$ latent values of the predicted outputs
<code>Y</code>	$N \times 1$ of true class labels
<code>figure(*)</code>	'figure'(*) or 'nofigure'

- Using the functional interface for the LS-SVMs:

```
>> [area, se, thresholds, oneMinusSpec, sens, TN, TP, FN, FP] = ...
    roc({X,Y,'classifier',gam,sig2,kernel})
>> [area, se, thresholds, oneMinusSpec, sens, TN, TP, FN, FP] = ...
    roc({X,Y,'classifier',gam,sig2,kernel}, figure)
```

#### Outputs

<code>area(*)</code>	Area under the ROC curve
<code>se(*)</code>	Standard deviation of the residuals
<code>thresholds(*)</code>	Different thresholds
<code>oneMinusSpec(*)</code>	1-Specificity of each threshold value
<code>sens(*)</code>	Sensitivity for each threshold value
<code>TN(*)</code>	Number of true negative predictions
<code>TP(*)</code>	Number of true positive predictions
<code>FN(*)</code>	Number of false negative predictions
<code>FP(*)</code>	Number of false positive predictions

#### Inputs

<code>X</code>	$N \times d$ matrix of the training data
<code>Y</code>	$N \times 1$ vector of the training data
<code>type</code>	'classifier' ('c')
<code>gam</code>	Regularization parameter
<code>sig2</code>	Kernel parameter(s) (for linear kernel, use [])
<code>kernel(*)</code>	Kernel type (by default 'RBF_kernel')
<code>preprocess(*)</code>	'preprocess'(*) or 'original'
<code>figure(*)</code>	'figure'(*) or 'nofigure'

- Using the object oriented interface for the LS-SVMs:

```
>> [area, se, thresholds, oneMinusSpec, sens, TN, TP, FN, FP] = roc(model)
>> [area, se, thresholds, oneMinusSpec, sens, TN, TP, FN, FP] = roc(model, figure)
```

#### Outputs

<code>area(*)</code>	Area under the ROC curve
<code>se(*)</code>	Standard deviation of the residuals
<code>thresholds(*)</code>	$N \times 1$ vector with different thresholds
<code>oneMinusSpec(*)</code>	1-Specificity of each threshold value
<code>sens(*)</code>	Sensitivity for each threshold value
<code>TN(*)</code>	Number of true negative predictions
<code>TP(*)</code>	Number of true positive predictions
<code>FN(*)</code>	Number of false negative predictions
<code>FP(*)</code>	Number of false positive predictions

#### Inputs

<code>model</code>	Object oriented representation of the LS-SVM model
<code>figure(*)</code>	'figure'(*) or 'nofigure'

See also:

`deltablssvm`, `trainlssvm`

### A.3.34 `simlssvm`

#### Purpose

*Evaluate the LS-SVM at given points*

#### Basic syntax

```
>> Yt = simlssvm({X,Y,type,gam,sig2,kernel}, {alpha,b}, Xt)
>> Yt = simlssvm({X,Y,type,gam,sig2,kernel}, Xt)
>> Yt = simlssvm(model, Xt)
```

#### Description

The matrix `Xt` represents the points one wants to predict. The first cell contains all arguments needed for defining the LS-SVM (see also `trainlssvm`, `initlssvm`). The second cell contains the results of training this LS-SVM model. The cell syntax allows for flexible and consistent default handling.

#### Full syntax

- Using the functional interface:

```
>> [Yt, Zt] = simlssvm({X,Y,type,gam,sig2}, Xt)
>> [Yt, Zt] = simlssvm({X,Y,type,gam,sig2,kernel}, Xt)
>> [Yt, Zt] = simlssvm({X,Y,type,gam,sig2,kernel,preprocess}, Xt)
>> [Yt, Zt] = simlssvm({X,Y,type,gam,sig2,kernel}, {alpha,b}, Xt)
```

#### Outputs

<code>Yt</code>	<code>Nt</code> × <code>m</code> matrix with predicted output of test data
<code>Zt(*)</code>	<code>Nt</code> × <code>m</code> matrix with predicted latent variables of a classifier

#### Inputs

<code>X</code>	<code>N</code> × <code>d</code> matrix with the inputs of the training data
<code>Y</code>	<code>N</code> × <code>m</code> vector with the outputs of the training data
<code>type</code>	'function estimation' ('f') or 'classifier' ('c')
<code>gam</code>	Regularization parameter
<code>sig2</code>	Kernel parameter(s) (for linear kernel, use [])
<code>kernel(*)</code>	Kernel type (by default 'RBF_kernel')
<code>preprocess(*)</code>	'preprocess'(*) or 'original'
<code>alpha(*)</code>	Support values obtained from training
<code>b(*)</code>	Bias term obtained from training
<code>Xt</code>	<code>Nt</code> × <code>d</code> inputs of the test data

- Using the object oriented interface:

```
>> [Yt, Zt, model] = simlssvm(model, Xt)
```

#### Outputs

<code>Yt</code>	<code>Nt</code> × <code>m</code> matrix with predicted output of test data
<code>Zt(*)</code>	<code>Nt</code> × <code>m</code> matrix with predicted latent variables of a classifier
<code>model(*)</code>	Object oriented representation of the LS-SVM model

#### Inputs

<code>model</code>	Object oriented representation of the LS-SVM model
<code>Xt</code>	<code>Nt</code> × <code>d</code> matrix with the inputs of the test data

See also:

`trainlssvm`, `initlssvm`, `plotlssvm`, `code`, `changelssvm`

## Purpose

## Basic syntax

## Description

If one uses the object oriented interface (see also A.3.16), the training is done by

One implementation is included:

- This implementation allows to train a multidimensional output problem. If each output uses the same kernel type, kernel parameters and regularization parameter, this is straightforward. If not so, one can specify the different types and/or parameters as a row vector in the appropriate argument. Each dimension will be trained with the corresponding column in this vector.

```
>> [alpha, b] = trainlssvm({X, [Y_1 ... Y_d], type, ...
                             [ gam_1 ... gam_d], ...
                             [sig2_1 ... sig2_d], ...
                             {kernel_1,...,kernel_d}})
```

**Full syntax**

- Using the functional interface:

```
>> [alpha, b] = trainlssvm({X,Y,type,gam,sig2})
>> [alpha, b] = trainlssvm({X,Y,type,gam,sig2,kernel})
>> [alpha, b] = trainlssvm({X,Y,type,gam,sig2,kernel,preprocess})
```

**Outputs**

alpha	N×m matrix with support values of the LS-SVM
b	1×m vector with bias term(s) of the LS-SVM

**Inputs**

X	N×d matrix with the inputs of the training data
Y	N×m vector with the outputs of the training data
type	'function estimation' ('f') or 'classifier' ('c')
gam	Regularization parameter
sig2	Kernel parameter(s) (for linear kernel, use [])
kernel(*)	Kernel type (by default 'RBF_kernel')
preprocess(*)	'preprocess'(*) or 'original'

- Using the object oriented interface:

```
>> model = trainlssvm(model)
>> model = trainlssvm({X,Y,type,gam,sig2})
>> model = trainlssvm({X,Y,type,gam,sig2,kernel})
>> model = trainlssvm({X,Y,type,gam,sig2,kernel,preprocess})
```

**Outputs**

model(*)	Trained object oriented representation of the LS-SVM model
----------	--

**Inputs**

model	Object oriented representation of the LS-SVM model
X(*)	N×d matrix with the inputs of the training data
Y(*)	N×m vector with the outputs of the training data
type(*)	'function estimation' ('f') or 'classifier' ('c')
gam(*)	Regularization parameter
sig2(*)	Kernel parameter(s) (for linear kernel, use [])
kernel(*)	Kernel type (by default 'RBF_kernel')
preprocess(*)	'preprocess'(*) or 'original'

**See also:**

simlssvm, initlssvm, changelssvm, plotlssvm, prelssvm, codelssvm



In case of the polynomial (degree is automatically tuned) and robust 10-fold cross-validation (combined with logistic weights):

```
>> [gam, sig2] = tunelssvm({X,Y,'f',[[],[]],'poly_kernel'}, 'simplex',...
    'rcrossvalidatelssvm', {10,'mae'},'wlogistic')
```

In the case of classification (notice the use of the function `misclass`)

```
>> gam = tunelssvm({X,Y,'c',[[],[]],'lin_kernel'}, 'simplex',...
    'leaveoneoutlssvm', {'misclass'});
>> gam = tunelssvm({X,Y,'c',[[],[]],'lin_kernel'}, 'linesearch',...
    'leaveoneoutlssvm', {'misclass'});
```

In the case of the RBF kernel where the 10-fold cross-validation cost function is the number of misclassifications (`misclass`):

```
>> [gam,sig2] = tunelssvm({X,Y,'c',[[],[]],'RBF_kernel'}, 'simplex',...
    'crossvalidatelssvm',{10,'misclass'});
>> [gam,sig2] = tunelssvm({X,Y,'c',[[],[]],'RBF_kernel'}, 'gridsearch',...
    'crossvalidatelssvm',{10,'misclass'})
```

The most simple algorithm to determine the minimum of a cost function with possibly multiple optima is to evaluate a grid over the parameter space and to pick the minimum. This procedure iteratively zooms to the candidate optimum. The StartingValues determine the limits of the grid over parameter space.

```
>> Xopt = gridsearch(fun, StartingValues)
```

This optimization function can be customized by passing extra options and the corresponding value. **These options cannot be changed in the `tunelssvm` command. The default values of `gridsearch`, `linesearch` or `simplex` are used when invoking `tunelssvm`.**

```
>> [Xopt, Yopt, Evaluations, fig] = gridsearch(fun, startvalues, funargs,...
    option1,value1,...)
```

the possible options and their default values are:

```
'nofigure'    ='figure';
'maxFunEvals' = 190;
'TolFun'      = .0001;
'TolX'        = .0001;
'grain'       = 10;
'zoomfactor'  = 5;
```

An example is given:

```
>> fun = inline('1-exp(-norm([X(1) X(2)]))','X');
>> gridsearch(fun,[-4 3; 2 -3])
```

the corresponding grid which is evaluated is shown in Figure A.1.

```
>> gridsearch(fun,[-3 3; 3 -3],{},'nofigure','nofigure','MaxFunEvals',1000)
```



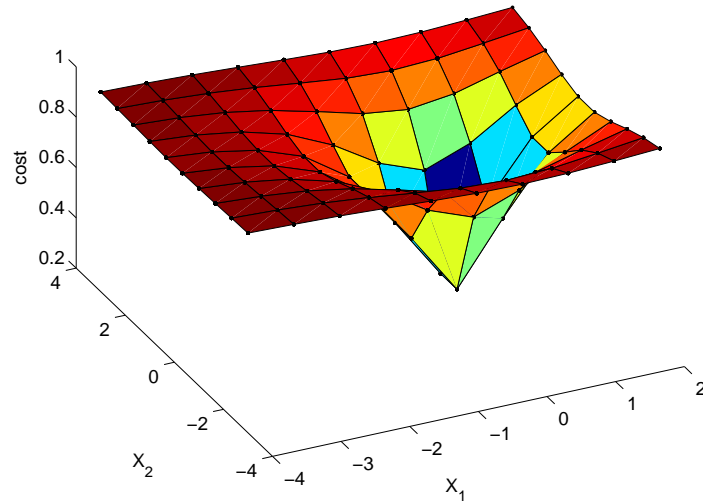


Figure A.1: This figure shows the grid which is optimized given the limit values  $[-4 \ 3; \ 2 \ -3]$ .

### Full syntax

- Optimization by exhaustive search over a two-dimensional grid:

```
>> [Xopt, Yopt, Evaluations, fig] = gridsearch(fun, startvalues, funargs,...
                                              option1,value1,...)
```

#### Outputs

Xopt	Optimal parameter set
Yopt	Criterion evaluated at Xopt
Evaluations	Used number of iterations
fig	Handle to the figure of the optimization

#### Inputs

CostFunction	Function implementing the cost criterion
StartingValues	2*d matrix with limit values of the widest grid
FunArgs(*)	Cell with optional extra function arguments of fun
option(*)	The name of the option one wants to change
value(*)	The new value of the option one wants to change

The different options:	<code>'Nofigure'</code>	<code>'figure'(*)</code> or <code>'nofigure'</code>
	<code>'MaxFunEvals'</code>	Maximum number of function evaluations (default: 100)
	<code>'GridReduction'</code>	grid reduction parameter (e.g. <code>'2'</code> : small reduction; <code>'10'</code> : heavy reduction; default <code>'5'</code> )
	<code>'TolFun'</code>	Minimal toleration of improvement on function value (default: 0.0001)
	<code>'TolX'</code>	Minimal toleration of improvement on X value (default: 0.0001)
	<code>'Grain'</code>	Square root number of function evaluations in one grid (default: 10)

- Optimization by exhaustive search of linesearch:

```
>> [Xopt, Yopt, Evaluations, fig] = linesearch(fun, startvalues, funargs,...
                                             option1,value1,...)
```

#### Outputs

<code>Xopt</code>	Optimal parameter set
<code>Yopt</code>	Criterion evaluated at <code>Xopt</code>
<code>iterations</code>	Used number of iterations
<code>fig</code>	Handle to the figure of the optimization

#### Inputs

<code>CostFun</code>	Function implementing the cost criterion
<code>StartingValues</code>	2*d matrix with limit values of the widest grid
<code>FunArgs(*)</code>	Cell with optional extra function arguments of <code>fun</code>
<code>option(*)</code>	The name of the option one wants to change
<code>value(*)</code>	The new value of the option one wants to change

The different options:	<code>'Nofigure'</code>	<code>'figure'(*)</code> or <code>'nofigure'</code>
	<code>'MaxFunEvals'</code>	Maximum number of function evaluations (default: 20)
	<code>'GridReduction'</code>	grid reduction parameter (e.g. <code>'1.5'</code> : small reduction; <code>'10'</code> : heavy reduction; default <code>'2'</code> )
	<code>'TolFun'</code>	Minimal toleration of improvement on function value (default: 0.01)
	<code>'TolX'</code>	Minimal toleration of improvement on X value (default: 0.01)
	<code>'Grain'</code>	Number of evaluations per iteration (default: 10)

#### Full syntax

- **SIMPLEX** - multidimensional unconstrained non-linear optimization. Simplex finds a local minimum of a function, via a function handle `fun`, starting from an initial point `X`. The local minimum is located via the Nelder-Mead simplex algorithm [23], which does not require any gradient information. `opt` contains the user specified options via a structure. The different options are set via a structure with members denoted by `opt.*`

```
>> Xopt = simplex(fun,X,opt)
```

• The different options:	<code>opts.Chi</code>	Parameter governing expansion steps (default: 2)
	<code>opts.Delta</code>	Parameter governing size of initial simplex (default: 1.2)
	<code>opts.Gamma</code>	Parameter governing contraction steps (default: 0.5)
	<code>opts.Rho</code>	Parameter governing reflection steps (default: 1)
	<code>opts.Sigma</code>	Parameter governing shrinkage steps (default: 0.5)
	<code>opts.MaxIter</code>	Maximum number of optimization steps (default: 15)
	<code>opts.MaxFunEvals</code>	Maximum number of function evaluations (default: 25)
	<code>opts.TolFun</code>	Stopping criterion based on the relative change in value of the function in each step (default: 1e-6)
	<code>opts.TolX</code>	Stopping criterion based on the change in the minimizer in each step (default: 1e-6)

**See also:**

`trainlssvm`, `crossvalidate`

### A.3.37 windowize & windowizeNARX

#### Purpose

*Re-arrange the data points into a (block) Hankel matrix for (N)AR(X) time-series modeling*

#### Basic Syntax

```
>> w = windowize(A, window)
>> [Xw,Yw] = windowizeNARX(X,Y,xdelays, ydelays, steps)
```

#### Description

Use `windowize` function to make a nonlinear AR predictor with a nonlinear regressor. The last elements of the resulting matrix will contain the future values of the time-series, the others will contain the past inputs. `window` is the relative index of data points in matrix `A`, that are selected to make a window. Each window is put in a row of matrix `W`. The matrix `W` contains as many rows as there are different windows selected in `A`.

Schematically, this becomes

```
>> A = [a1 a2 a3;
        b1 b2 b3;
        c1 c2 c3;
        d1 d2 d3;
        e1 e2 e3;
        f1 f2 f3;
        g1 g2 g3];

>> W = windowize(A, [1 2 3])

W =
a1 a2 a3  b1 b2 b3  c1 c2 c3
b1 b2 b3  c1 c2 c3  d1 d2 d3
c1 c2 c3  d1 d2 d3  e1 e2 e3
d1 d2 d3  e1 e2 e3  f1 f2 f3
e1 e2 e3  f1 f2 f3  g1 g2 g3
```

The function `windowizeNARX` converts the time-series and its exogeneous variables into a block Hankel format useful for training a nonlinear function approximation as a nonlinear ARX model.

#### Full syntax

- >> Xw = windowize(X, window)

The length of `window` is denoted by `w`.

#### Outputs

Xw (N-w+1) × w — matrix of the sequences of windows over X

#### Inputs

X N × 1 vector with data points

w w × 1 vector with the relative indices of one window

- >> [Xw, Yw, xdim, ydim, n] = windowizeNARX(X, Y, xdelays, ydelays)
- >> [Xw, Yw, xdim, ydim, n] = windowizeNARX(X, Y, xdelays, ydelays, steps)

**Outputs**

<b>Xw</b>	Matrix of the data used for input including the delays
<b>Yw</b>	Matrix of the data used for output including the next steps
<b>xdim(*)</b>	Number of dimensions in new input
<b>ydim(*)</b>	Number of dimensions in new output
<b>n(*)</b>	Number of new data points

**Inputs**

<b>X</b>	$N \times m$ vector with input data points
<b>Y</b>	$N \times d$ vector with output data points
<b>xdelays</b>	Number of lags of <b>X</b> in new input
<b>ydelays</b>	Number of lags of <b>Y</b> in new input
<b>steps(*)</b>	Number of future steps of <b>Y</b> in new output (by default 1)

**See also:**

`windowizeNARX`, `predict`, `trainlssvm`, `simlssvm`



# Bibliography

- [1] Alzate C. and Suykens J.A.K. (2008), “Kernel Component Analysis using an Epsilon Insensitive Robust Loss Function”, *IEEE Transactions on Neural Networks*, **19**(9), 1583–1598.
- [2] Alzate C. and Suykens J.A.K. (2010), “Multiway Spectral Clustering with Out-of-Sample Extensions through Weighted Kernel PCA”, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, **32**(2), 335–347.
- [3] Baudat G., Anouar F. (2001), “Kernel-based methods and function approximation”, in *International Joint Conference on Neural Networks (IJCNN 2001)*, Washington DC USA, 1244–1249.
- [4] Cawley G.C., Talbot N.L.C. (2002), “Efficient formation of a basis in a kernel induced feature space”, in *Proc. European Symposium on Artificial Neural Networks (ESANN 2002)*, Brugge Belgium, 1–6.
- [5] Cristianini N., Shawe-Taylor J. (2000), *An Introduction to Support Vector Machines*, Cambridge University Press.
- [6] De Brabanter J., Pelckmans K., Suykens J.A.K., Vandewalle J. (2002), “Robust cross-validation score function for LS-SVM non-linear function estimation”, *International Conference on Artificial Neural Networks (ICANN 2002)*, Madrid Spain, Madrid, Spain, Aug. 2002, 713–719.
- [7] De Brabanter K., Pelckmans K., De Brabanter J., Debruyne M., Suykens J.A.K., Hubert M., De Moor B. (2009), “Robustness of Kernel Based Regression: a Comparison of Iterative Weighting Schemes”, *Proc. of the 19th International Conference on Artificial Neural Networks (ICANN)*, Limassol, Cyprus, September, 100–110.
- [8] De Brabanter K., De Brabanter J., Suykens J.A.K., De Moor B. (2010), “Optimized Fixed-Size Kernel Models for Large Data Sets”, *Computational Statistics & Data Analysis*, **54**(6), 1484–1504.
- [9] De Brabanter K., De Brabanter J., Suykens J.A.K., De Moor B. (2010), “Approximate Confidence and Prediction Intervals for Least Squares Support Vector Regression”, *Technical Report*, 10-156.
- [10] Evgeniou T., Pontil M., Poggio T. (2000), “Regularization networks and support vector machines,” *Advances in Computational Mathematics*, **13**(1), 1–50.
- [11] Fawcett T. (2006) “An Introduction to ROC analysis”, *Pattern Recognition Letters*, **27**, 861–874.
- [12] Girolami M. (2002), “Orthogonal series density estimation and the kernel eigenvalue problem”, *Neural Computation*, **14**(3), 669–688.
- [13] Golub G.H. and Van Loan C.F. (1989), *Matrix Computations*, Johns Hopkins University Press, Baltimore, MD.

- [14] Györfi L., Kohler M., Krzyżak A., Walk H. (2002), *A Distribution-Free Theory of Nonparametric Regression*, Springer
- [15] Hall, P. (1992), "On Bootstrap Confidence Intervals in Nonparametric Regression," *Annals of Statistics*, **20**(2), 695–711.
- [16] Hanley J.A., McNeil B.J. (1982), "The meaning and use of the area under a receiver operating characteristic (ROC) curve" *Radiology* 1982; **143**, 29-36.
- [17] Huber P.J. (1964), "Robust estimation of a location parameter", *Ann. Math. Statist.*, **35**, 73–101.
- [18] Loader C. (1999), *Local Regression and Likelihood*, Springer-Verlag.
- [19] MacKay D.J.C. (1992), "Bayesian interpolation", *Neural Computation*, **4**(3), 415–447.
- [20] Mika S., Schölkopf B., Smola A., Müller K.-R., Scholz M., Ratsch G. (1999), "Kernel PCA and de-noising in feature spaces", *Advances in Neural Information Processing Systems 11*, 536–542, MIT Press.
- [21] Mika S., Rätsch G., Weston J., Schölkopf B., Müller K.-R. (1999), "Fisher discriminant analysis with kernels", In *Neural Networks for Signal Processing IX*, 41–48, IEEE.
- [22] Nabney I.T. (2002), *Netlab: Algorithms for Pattern Recognition*, Springer.
- [23] Nelder J. A. and Mead R., (1965) "A simplex method for function minimization", *Computer Journal*, **7**, 308-313.
- [24] Poggio T., Girosi F. (1990), "Networks for approximation and learning", *Proc. of the IEEE*, **78**, 1481–1497.
- [25] Rice S.O. (1939), "The distribution of the maxima of a random curve," *American Journal of Mathematics*, **61**(2), 409-416.
- [26] Ruppert D., Wand M.P. and Carroll R.J. (2003), *Semiparametric Regression*, Cambridge University Press.
- [27] Schölkopf B., Burges C., Smola A. (Eds.) (1998), *Advances in Kernel Methods - Support Vector Learning*, MIT Press.
- [28] Schölkopf B., Smola A. J., Müller K.-R. (1998), "Nonlinear component analysis as a kernel eigenvalue problem", *Neural Computation*, **10**, 1299–1319.
- [29] Schölkopf B., Smola A. (2002), *Learning with Kernels*, MIT Press.
- [30] Smola A.J., Schölkopf B. (2000), "Sparse greedy matrix approximation for machine learning", *Proc. 17th International Conference on Machine Learning*, 911–918, San Francisco, Morgan Kaufman.
- [31] Stone M. (1974), "Cross-validated choice and assessment of statistical predictions", *J. Royal Statist. Soc. Ser. B*, **36**, 111–147.
- [32] Suykens J.A.K., Vandewalle J. (1999), "Least squares support vector machine classifiers", *Neural Processing Letters*, **9**(3), 293–300.
- [33] Suykens J.A.K., Vandewalle J. (2000), "Recurrent least squares support vector machines", *IEEE Transactions on Circuits and Systems-I*, **47**(7), 1109–1114.
- [34] Suykens J.A.K., De Brabanter J., Lukas L., Vandewalle J. (2002), "Weighted least squares support vector machines : robustness and sparse approximation", *Neurocomputing*, Special issue on fundamental and information processing aspects of neurocomputing, **48**(1-4), 85–105.



- [35] Suykens, J. A. K., Vandewalle, J., & De Moor, B. (2001), "Intelligence and cooperative search by coupled local minimizers", *International Journal of Bifurcation and Chaos*, **11**(8), 2133-2144.
- [36] Sun J. and Loader C.R. (1994), "Simultaneous confidence bands for linear regression and smoothing," *Annals of Statistics*, **22**(3), 1328-1345.
- [37] Suykens J.A.K., Van Gestel T., Vandewalle J., De Moor B. (2002), "A support vector machine formulation to PCA analysis and its Kernel version", *IEEE Transactions on Neural Networks*, **14**(2), 447-450.
- [38] Suykens J.A.K., Van Gestel T., De Brabanter J., De Moor B., Vandewalle J. (2002), *Least Squares Support Vector Machines*, World Scientific, Singapore.
- [39] Suykens J.A.K. (2008), "Data Visualization and Dimensionality Reduction using Kernel Maps with a Reference Point", *IEEE Transactions on Neural Networks*, **19**(9), 1501-1517.
- [40] Van Belle V., Pelckmans K., Suykens J.A.K., Van Huffel S. (2010), "Additive survival least squares support vector machines", *Statistics in Medicine*, **29**(2), 296-308.
- [41] Van Gestel T., Suykens J.A.K., Baestaens D., Lambrechts A., Lanckriet G., Vandaele B., De Moor B., Vandewalle J. (2001) "Financial time series prediction using least squares support vector machines within the evidence framework", *IEEE Transactions on Neural Networks* (special issue on Neural Networks in Financial Engineering), **12**(4), 809-821.
- [42] Van Gestel T., Suykens J.A.K., De Moor B., Vandewalle J. (2001), "Automatic relevance determination for least squares support vector machine classifiers", *Proc. of the European Symposium on Artificial Neural Networks* (ESANN 2001), Bruges, Belgium, 13-18.
- [43] Van Gestel T., Suykens J.A.K., Baesens B., Viaene S., Vanthienen J., Dedene G., De Moor B., Vandewalle J. (2001), "Benchmarking least squares support vector machine classifiers", *Machine Learning*, **54**(1), 5-32.
- [44] Van Gestel T., Suykens J.A.K., Lanckriet G., Lambrechts A., De Moor B., Vandewalle J. (2002), "Bayesian framework for least squares support vector machine classifiers, gaussian processes and kernel fisher discriminant analysis", *Neural Computation*, **15**(5), 1115-1148.
- [45] Van Gestel T., Suykens J.A.K., Lanckriet G., Lambrechts A., De Moor B., Vandewalle J. (2002), "Multiclass LS-SVMs : moderated outputs and coding-decoding schemes", *Neural Processing Letters*, **15**(1), 45-58.
- [46] Van Gestel T., Suykens J.A.K., De Moor B., Vandewalle J. (2002), "Bayesian inference for LS-SVMs on large data sets using the Nyström method", *International Joint Conference on Neural Networks* (WCCI-IJCNN 2002), Honolulu, USA, May 2002, 2779-2784.
- [47] Vapnik V. (1995), *The Nature of Statistical Learning Theory*, Springer-Verlag, New York.
- [48] Vapnik V. (1998), *Statistical Learning Theory*, John Wiley, New-York.
- [49] Williams C.K.I., Seeger M. (2001), "Using the Nyström method to speed up kernel machines", *Advances in neural information processing systems*, **13**, 682-688, MIT Press.
- [50] Wahba G., Wold S. (1975), "A completely automatic french curve: fitting spline functions by cross-validation", *Comm. Statist.*, **4**, 1-17.
- [51] Wahba G. (1990), *Spline Models for observational data*, SIAM, **39**.
- [52] Xavier de Souza, S., Suykens, J. A. K., Vandewalle, J., & Bollé, D. (2010), "Coupled Simulated Annealing", *IEEE Transactions on Systems, Man and Cybernetics - Part B*, **40**(2), 320-335.