LIBTwinSVM

A Library for Twin Support Vector Machines

Amir Mir

Software Engineering Research Group
EEMCS Faculty

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Contents

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Support Vector Machine (SVM)

- Introduced by Vapnik and Cortes [1] in 1995.
- Finds an optimal separating hyperplane.

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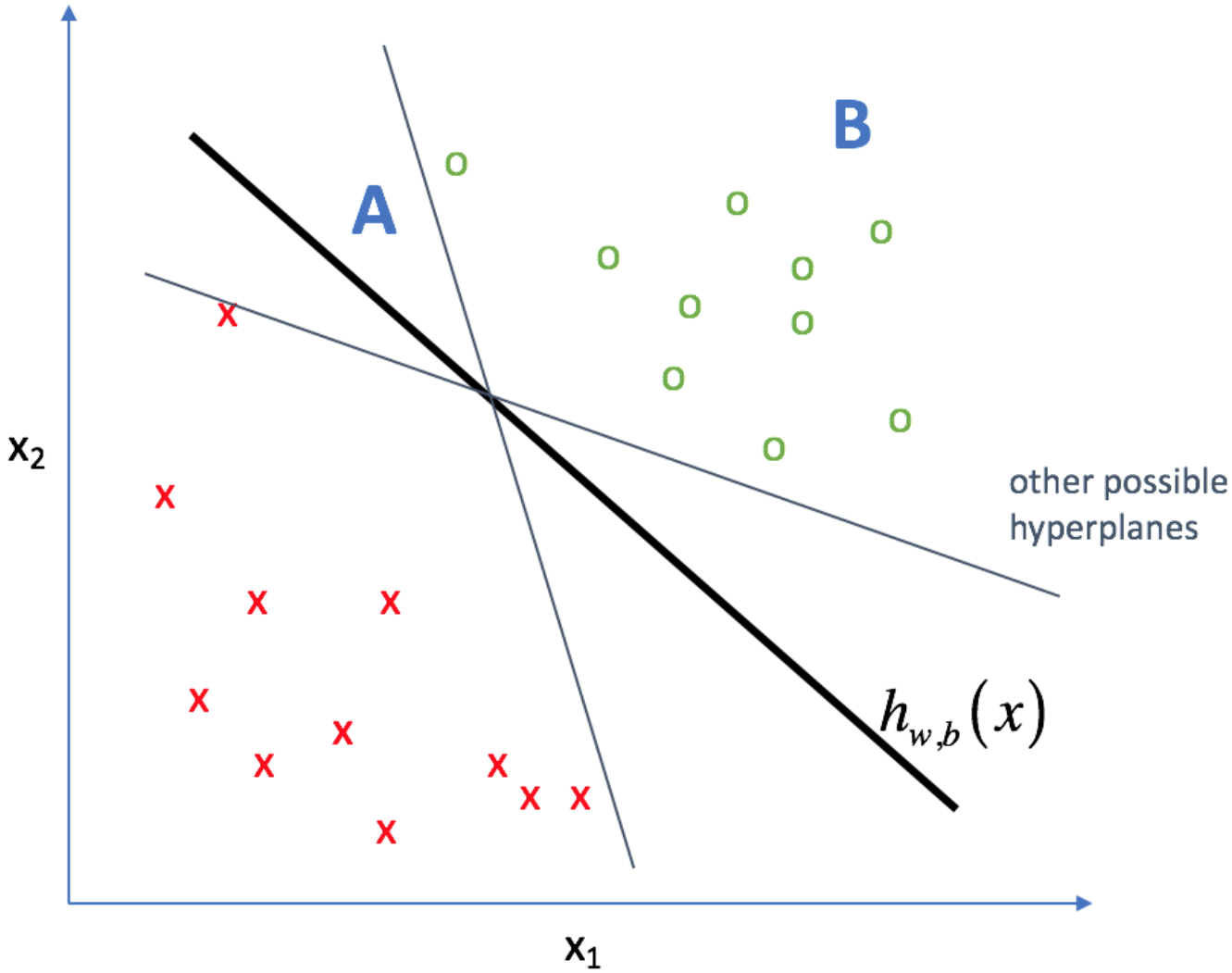
The Illustration of SVM's basic idea



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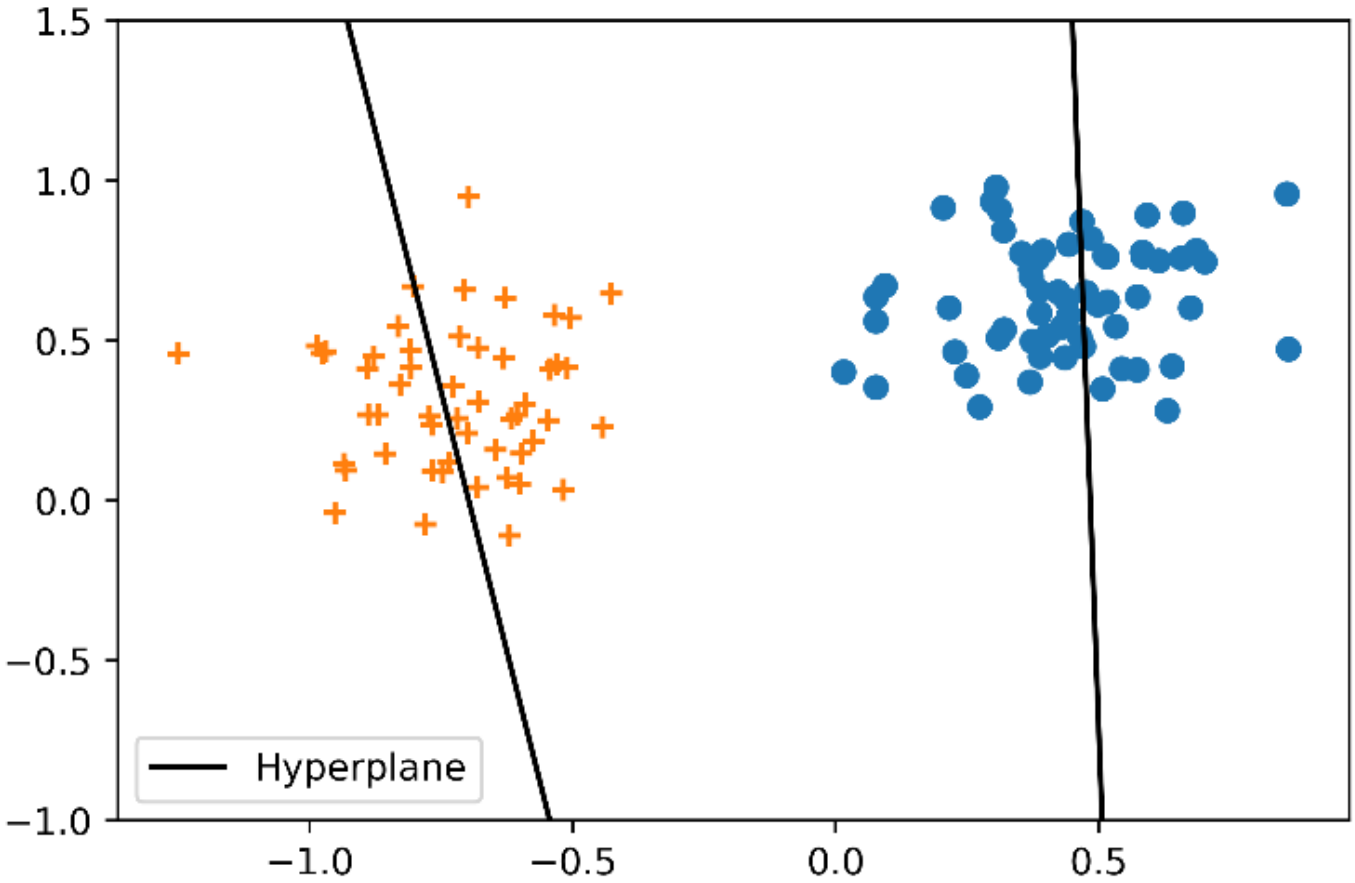

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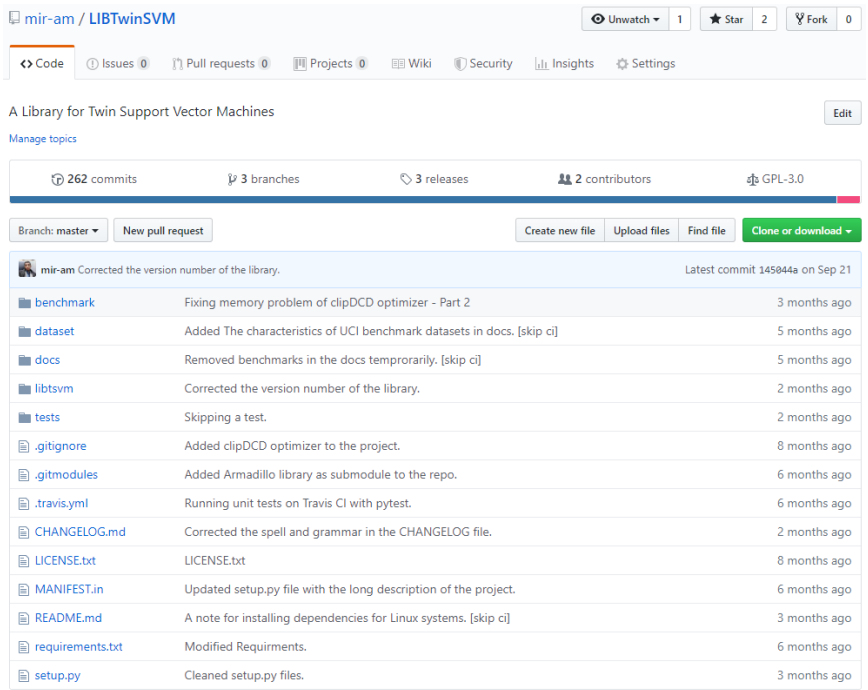

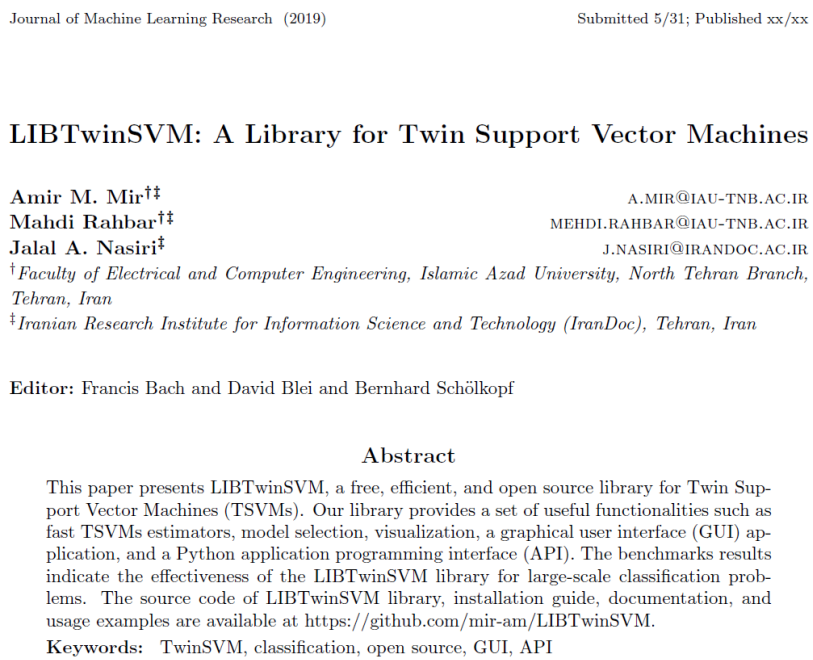

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LIBTwinSVM: A Library for Twin Support Vector Machines

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Jalal A. Nasiri[‡] J.NASIRI@IRANDOC.AC.IR
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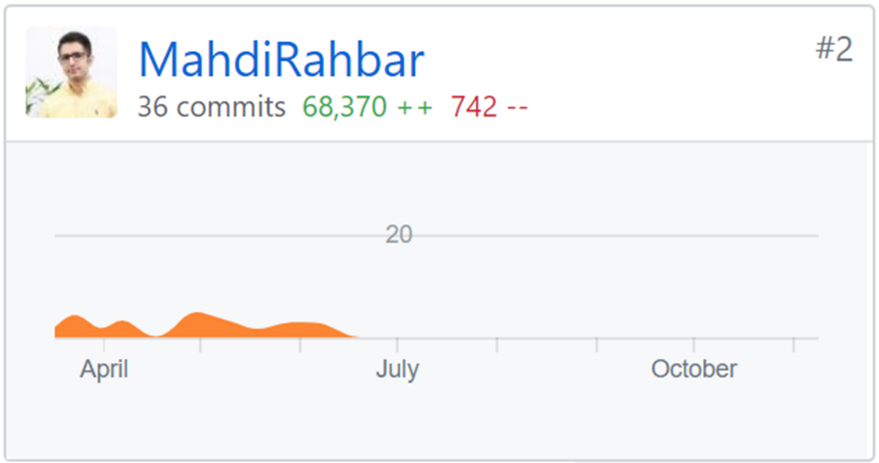
Abstract

This paper presents LIBTwinSVM, a free, efficient, and open source library for Twin Support Vector Machines (TSVMs). Our library provides a set of useful functionalities such as fast TSVMs estimators, model selection, visualization, a graphical user interface (GUI) application, and a Python application programming interface (API). The benchmarks results indicate the effectiveness of the LIBTwinSVM library for large-scale classification problems. The source code of LIBTwinSVM library, installation guide, documentation, and usage examples are available at https://github.com/mir-am/LIBTwinSVM.

Keywords: TwinSVM, classification, open source, GUI, API

Contributors of the LIBTwinSVM project



Dr. Jalal A. Nasiri

PhD in Computer Engineering; Tarbiat Modares University

- Assistant professor; Information Science Research Department
- j.nasiri@irandoc.ac.ir

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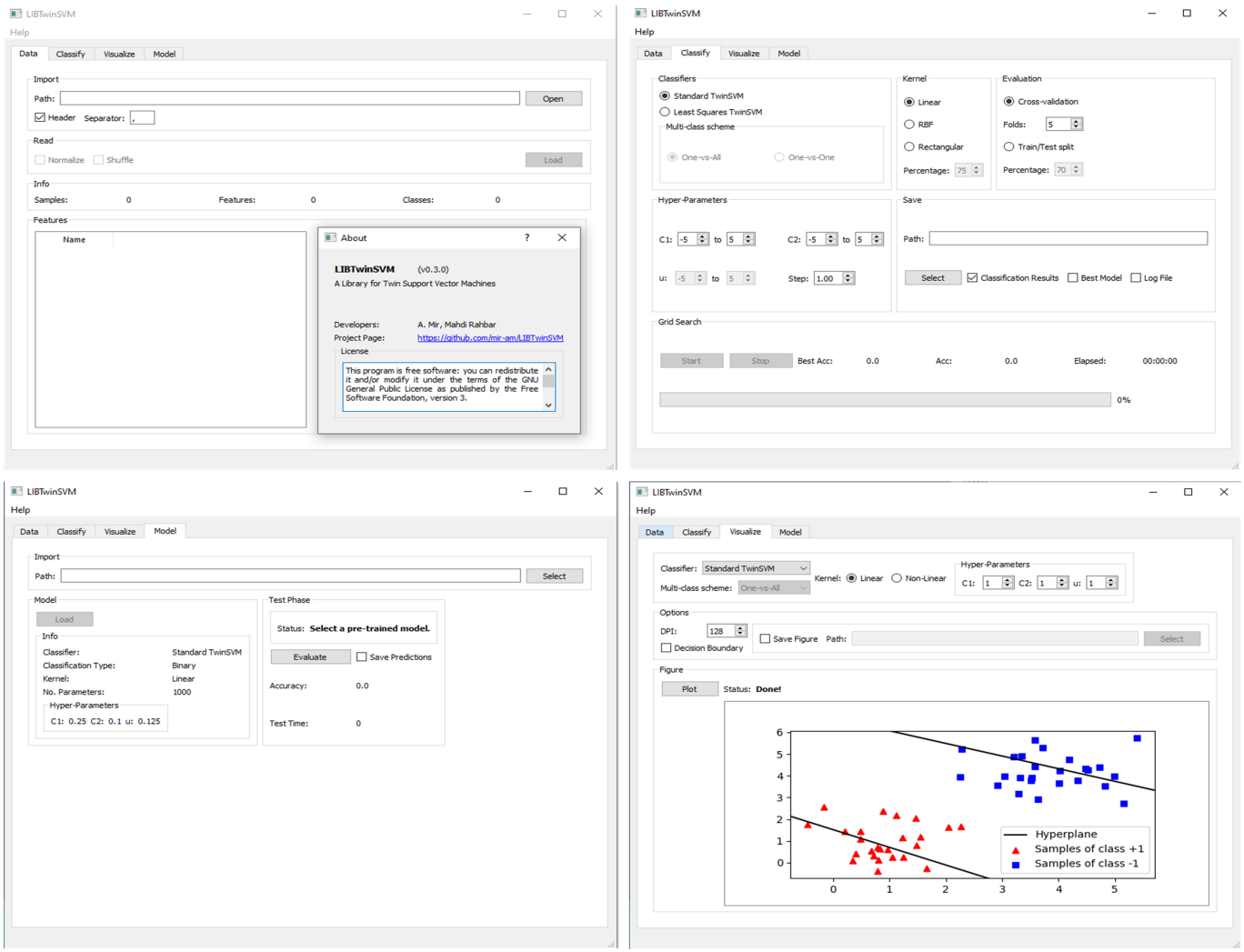

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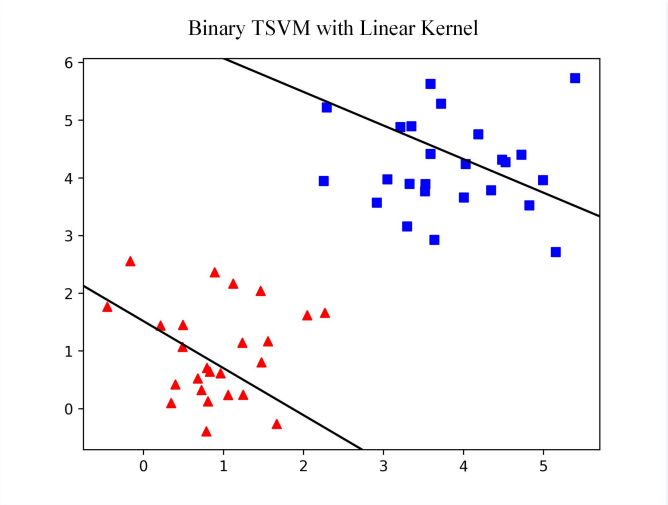

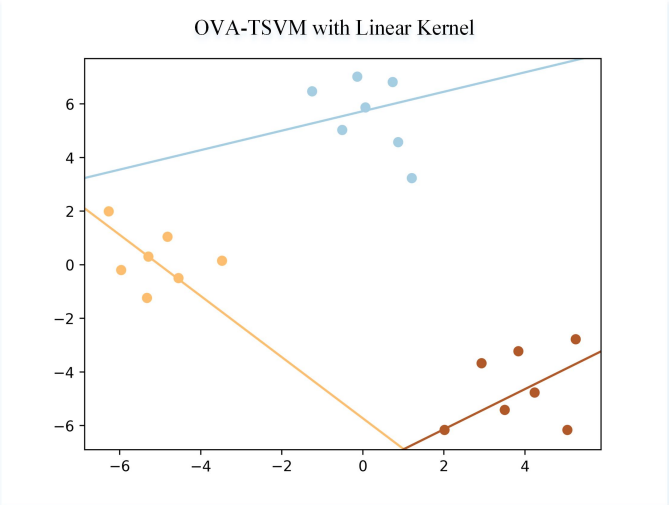

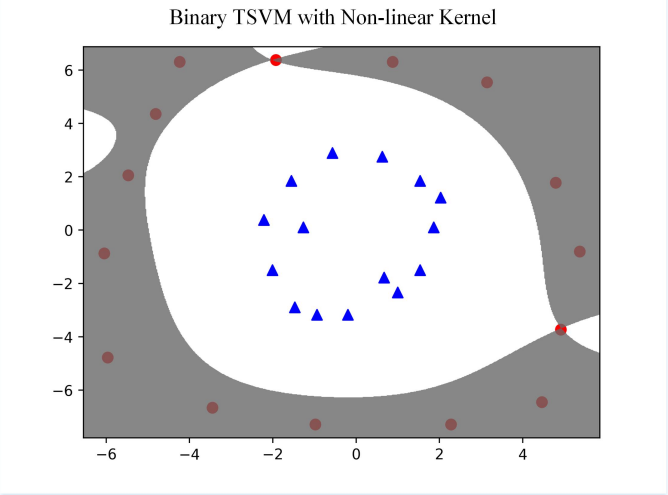

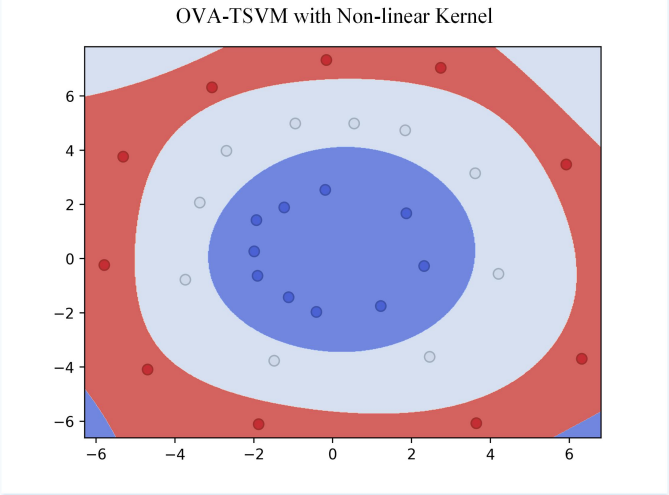

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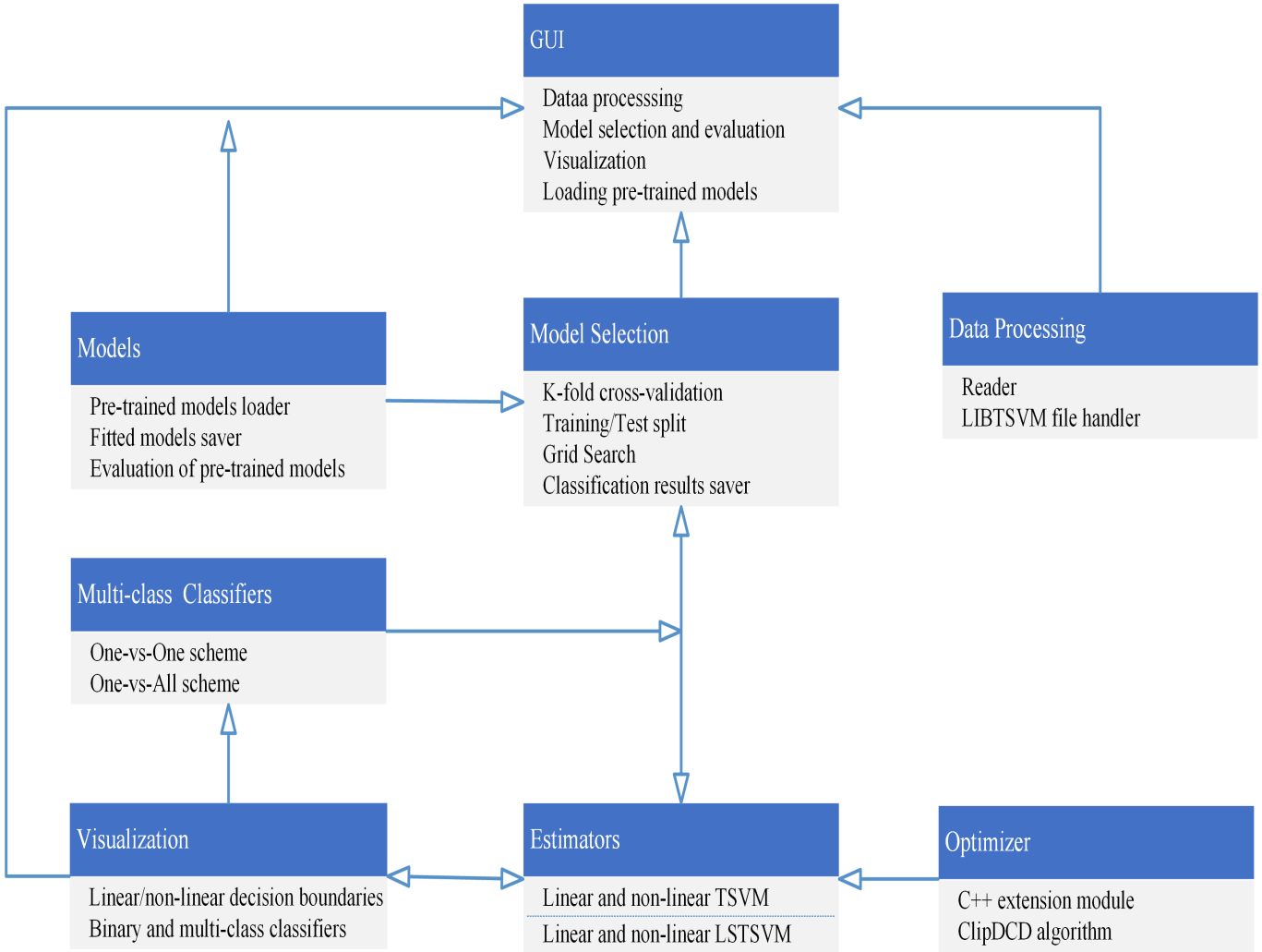

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- **Optimizer**: ClipDCD algorithm for solving optimization problems of TSVM.

Implementation

Dependencies of the LIBTwinSVM library

Package	Usage
	Python
NumPy	Fast linear algebra operations such as matrix multiplication and inverse
Scikit-learn	For the evaluation and selection of TSVM-based models
Matplotlib	Visualization and geometrical interpretation of TSVMs
PyQT5	A GUI for using the functionalities of the library
Pandas	For reading and processing datasets
XlsxWriter	For saving classification results in an Excel file
Joblib	For saving and loading TwinSVM-based models
numpydoc	API code documentation
	C++
Armadillo	C++ linear algebra library for optimizer component
LAPACK and BLAS	Numerical linear algebra.

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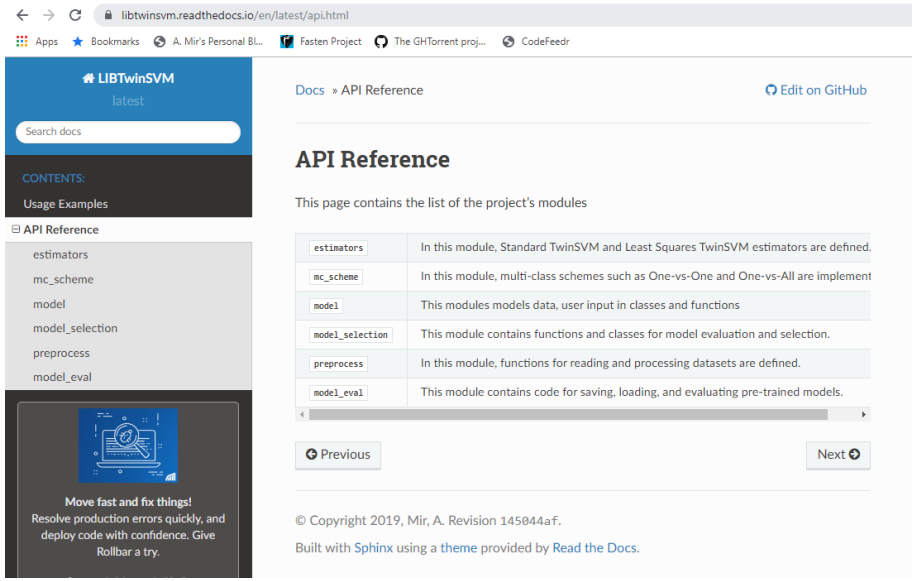

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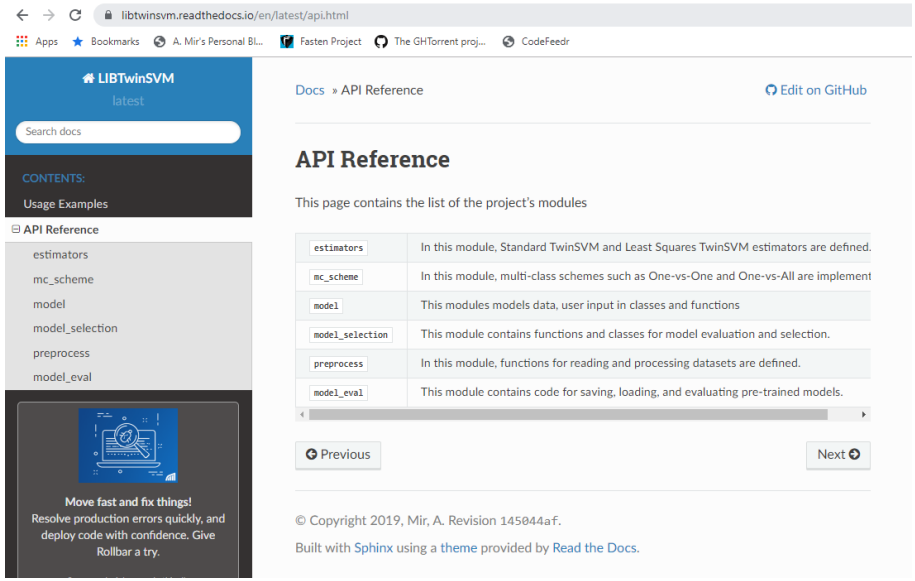

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API

Usage example

```
from libtsvm.preprocess import DataReader
from libtsvm.estimators import TSVM
from libtsvm.model_selection import Validator

# Step 1: Load your dataset
data_path = '../../dataset/australian.csv'
sep_char = ',' # separtor character of the CSV file
header = True # Whether the dataset has header names.

dataset = DataReader(data_path, sep_char, header)

shuffle_data = True
normalize_data = False

dataset.load_data(shuffle_data, normalize_data)
X, y, file_name = dataset.get_data()

# Step 2: Choose a TSVM-based estimator
kernel = 'linear'
tsvm_clf = TSVM(kernel=kernel)

# Step 3: Evaluate the estimator using train/test split
eval_method = 't_t_split' # Train/Test split
test_set_size = 30 # 30% of samples

val = Validator(X, y, (eval_method, test_set_size), tsvm_clf)
eval_func = val.choose_validator()

# Hyper-parameters of the classifier
h_params =  {'C1': 2**-3, 'C2': 2**-5}

acc, std, full_report = eval_func(h_params)

print("Accuracy: %.2f" % acc)
print(full_report)
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Benchmarks

Classification performance

Experiment details:

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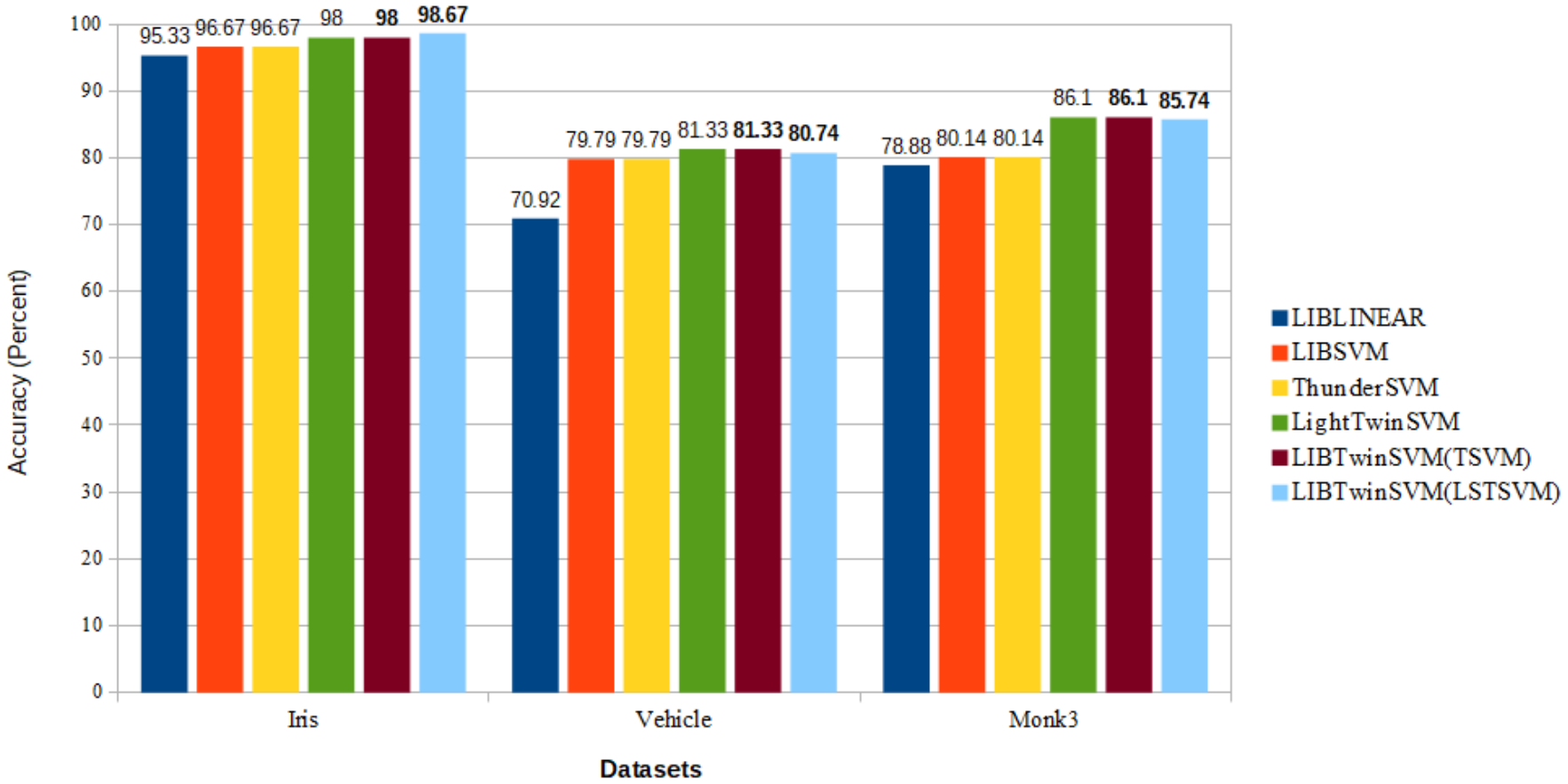

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NDC-50K dataset[9]

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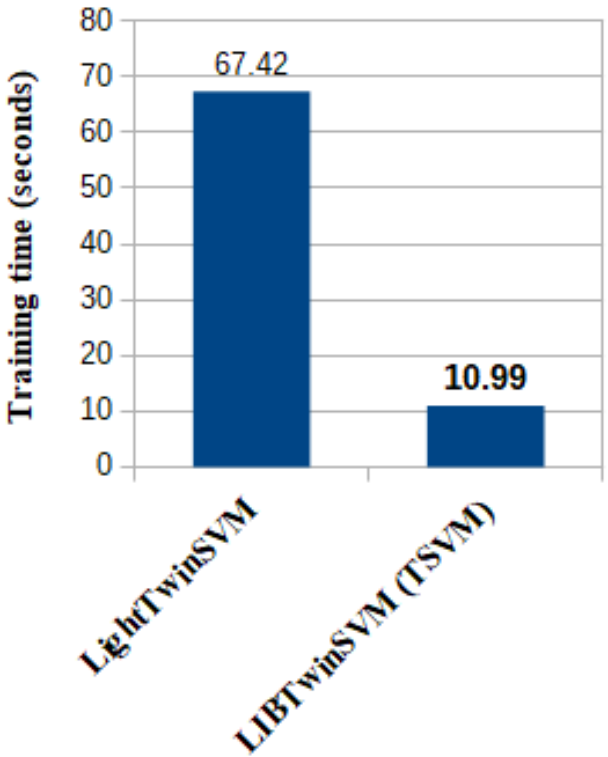

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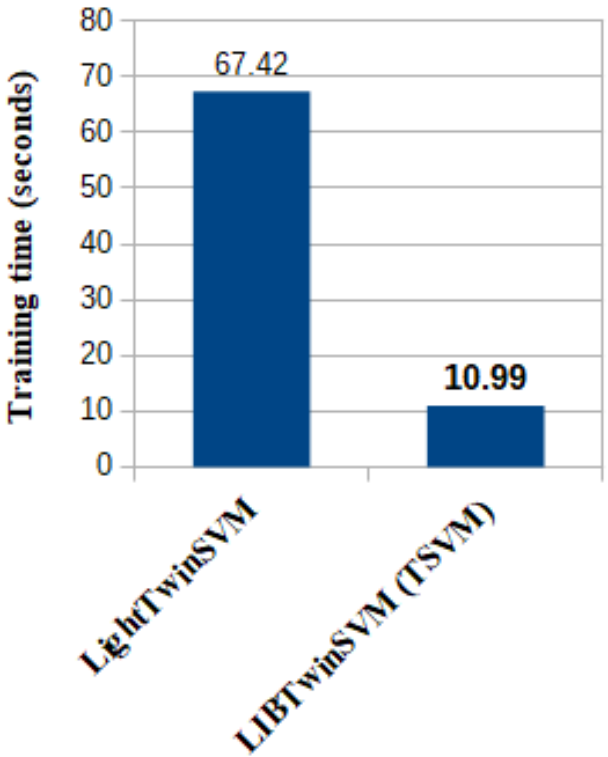
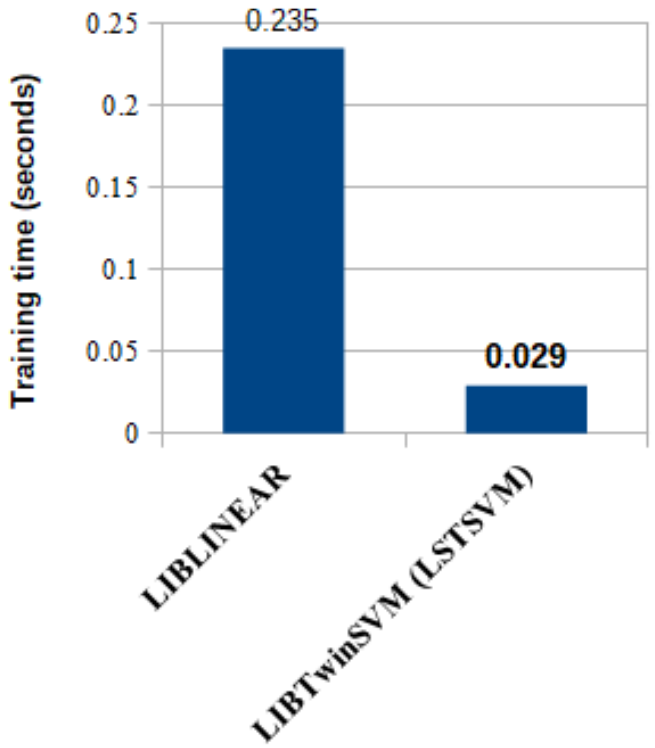


LIBLINEAR vs. LIBTwinSVM(LSTSVM)

About 8 times faster



[9] D. Musicant (1998). "NDC: normally distributed clustered datasets". In: *Computer Sciences Department, University of*

Benchmarks

Speed: Prediction time

NDC-50K dataset

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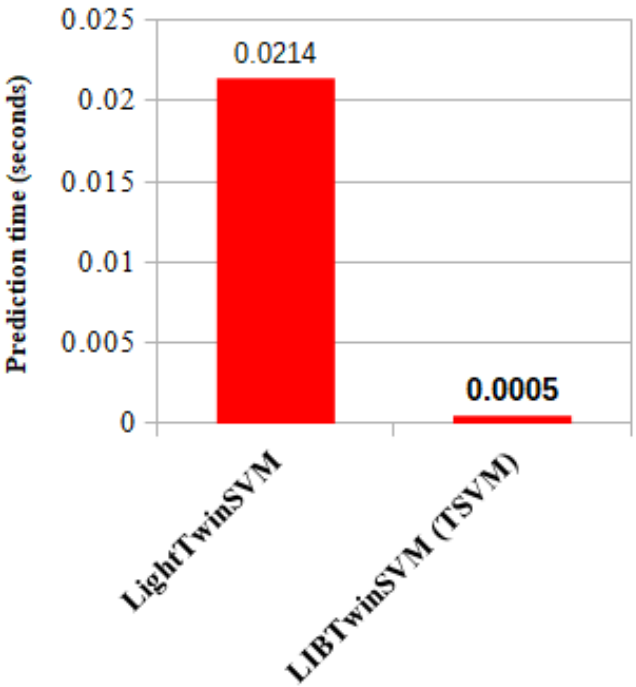
About 42 times improvement



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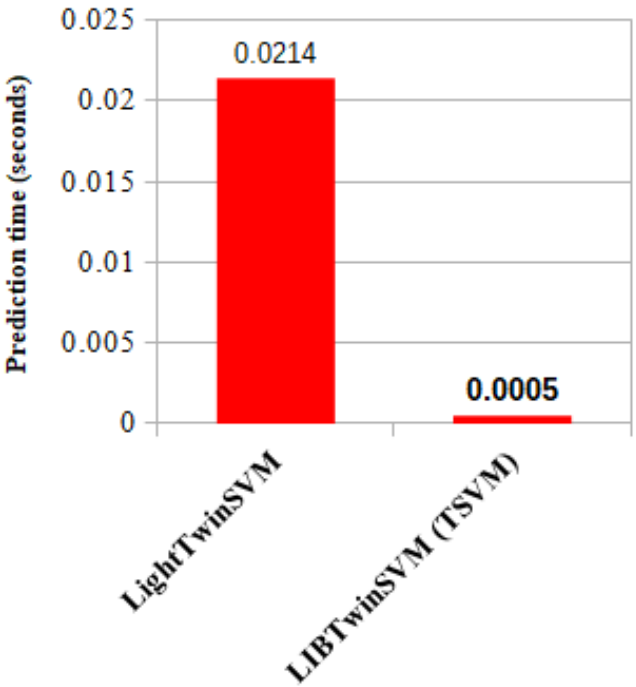
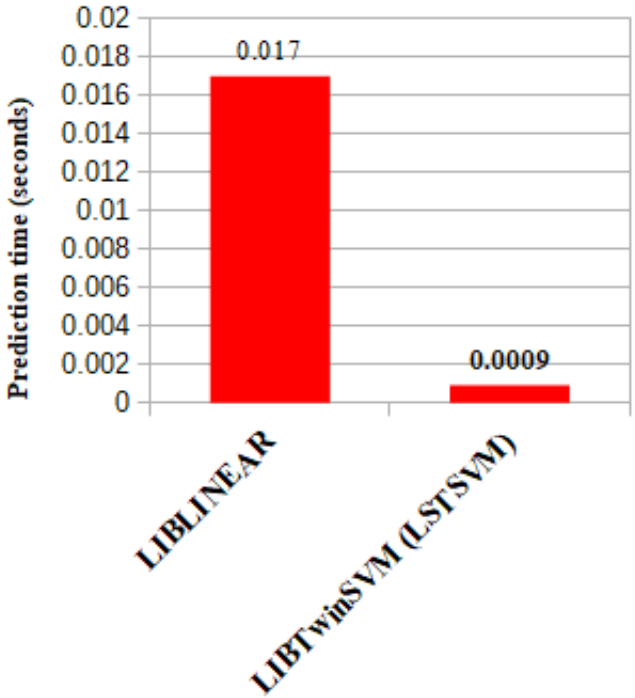


LIBLINEAR vs. LIBTwinSVM(LSTSVM)

About 18 times faster



Benchmarks

Memory consumption

Procedure for measuring the peak memory consumption:

- Loading a dataset.
- Training an estimator using `fit()` method.
- The Linux `time` command for measuring the usage.

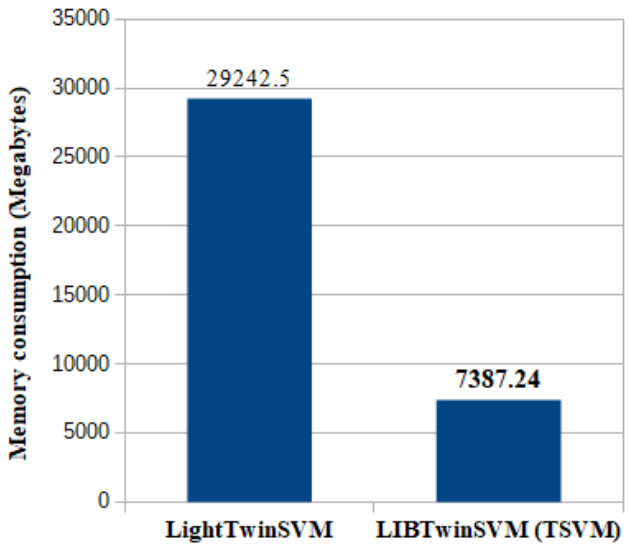
Benchmarks

Memory consumption

NDC-50K dataset

LightTwinSVM vs. LIBTwinSVM(TSVM)

About 4 times lower



Benchmarks

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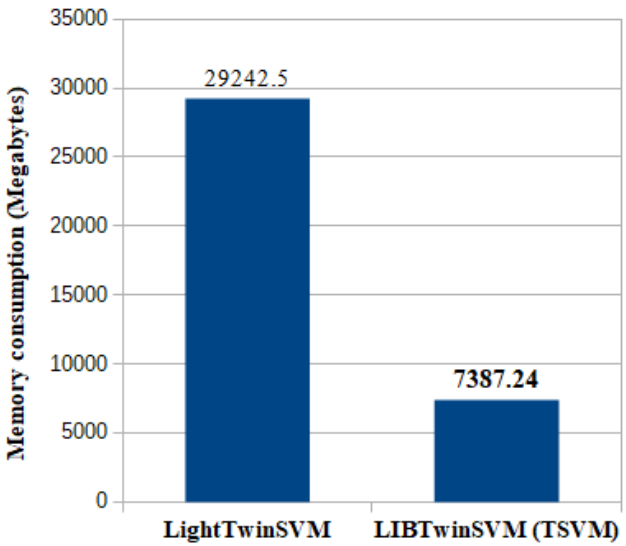
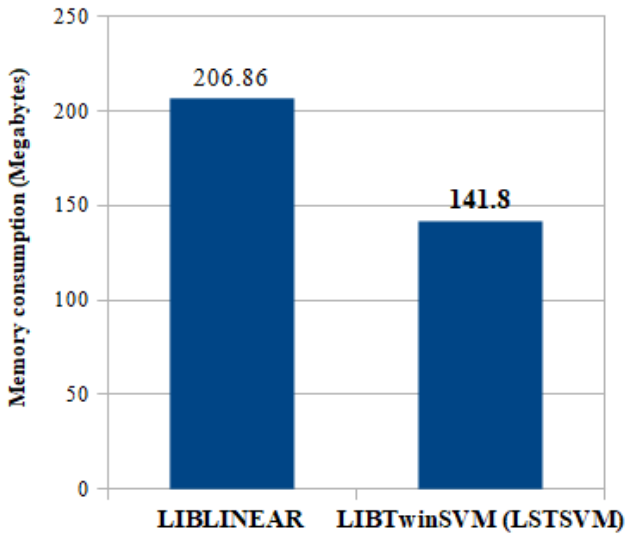


LIBLINEAR vs. LIBTwinSVM(LSTSVM)

About 45 percent lower



Solved Problems

The efficiency of the optimizer component

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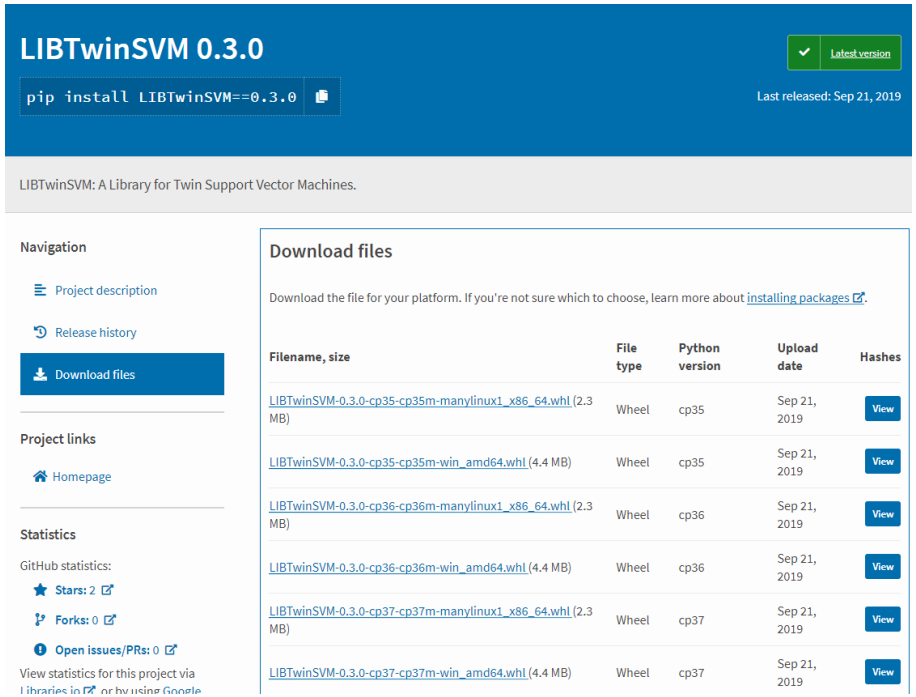
- A NumPy array to an Armadillo matrix without memory copy.

Solved Problems

Pre-built Python wheels

- Including the dependencies of the C++ extension module.



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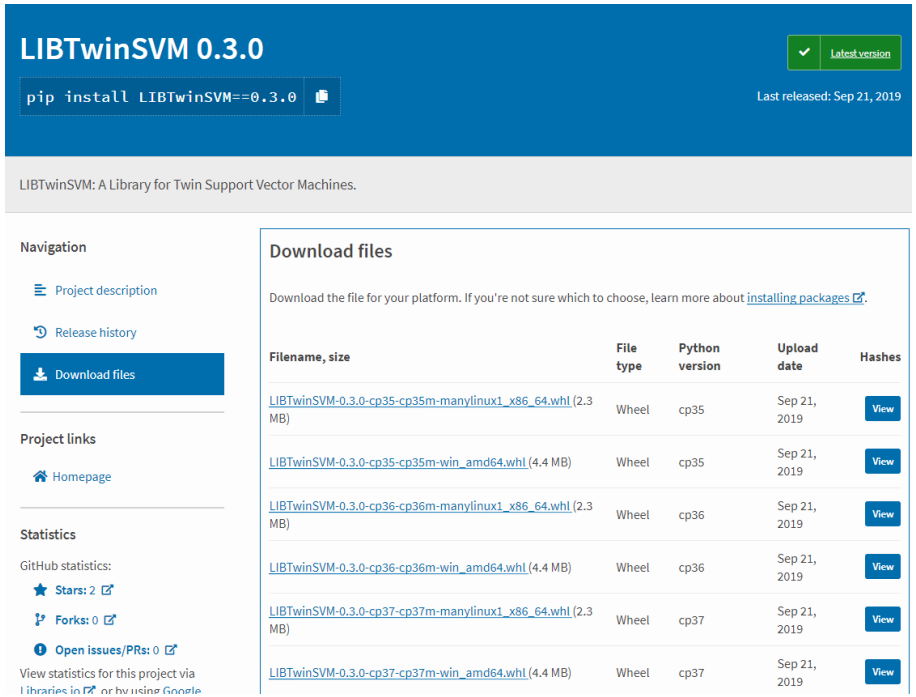

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Solved Problems

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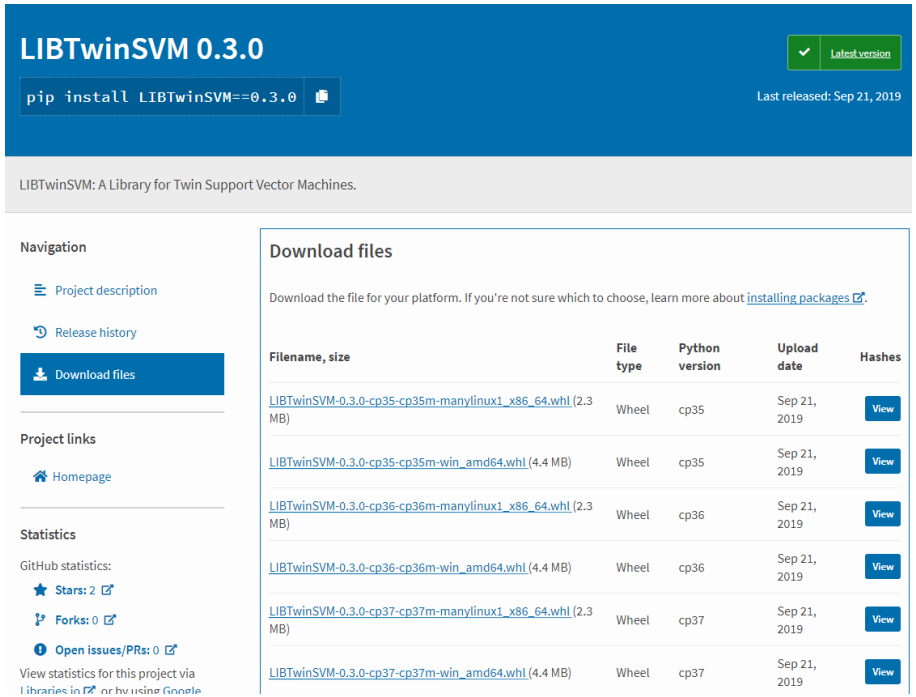
- Used **multibuild**[10] project.
- Employed Travis CI and AppVeyor for generating the wheels.



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Very high memory consumption

Optimized the `fit()` of the TSVM classifier by changing the order of the computation.

Previous approach

1. Compute the matrix of the **first** optimization problem.
2. Compute the matrix of the **second** optimization problem.
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Current approach

1. Compute the matrix of the **first** optimization problem.
2. Solve the first optimization problem.
3. Free the matrix of the first optimization problem from the memory.
4. Compute the matrix of the **second** optimization problem.
5. Solve the second optimization

Open problems

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- The library provides a GUI app and a Python API.
- The experimental results are comparable or even better.
- There are open problems to improve the library.

Quote

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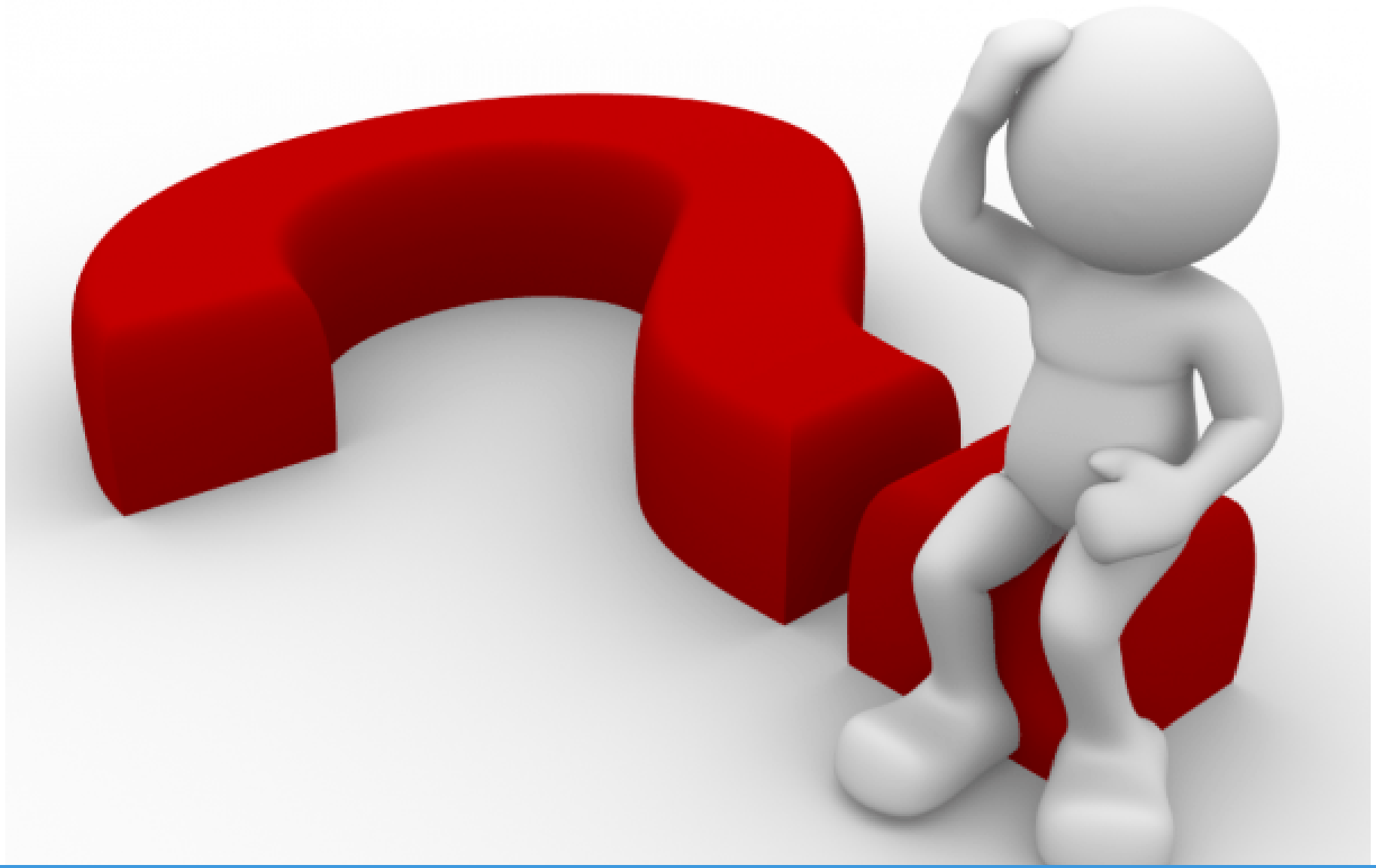
"We have to stop optimizing for programmers and start optimizing for users."

Jeff Atwood

Questions



References

Buitinck, L., G. Louppe, M. Blondel, F. Pedregosa, A. Mueller, O. Grisel, V. Niculae, P. Prettenhofer, A. Gramfort, J. Grobler, et al. (2013). "API design for machine learning software: experiences from the scikit-learn project". In: *arXiv preprint arXiv:1309.0238*.

Cortes, C. and V. Vapnik (1995). "Support-vector networks". In: *Machine learning* 20.3, pp. 273–297. ISSN: 0885-6125.

Khemchandani, R, S. Chandra, et al. (2007). "Twin support vector machines for pattern classification". In: *IEEE Transactions on pattern analysis and machine intelligence* 29.5, pp. 905–910.

Kumar, M. A. and M. Gopal (2009). "Least squares twin support vector machines for pattern classification". In: *Expert Systems with Applications* 36.4, pp. 7535–7543.

Mir, A. M. and J. A. Nasiri (2019). "LightTwinSVM: A Simple and Fast Implementation of Standard Twin Support Vector Machine Classifier". In: *Journal of Open Source Software* 4, p. 1252.

Musicant, D. (1998). "NDC: normally distributed clustered datasets". In: *Computer Sciences Department, University of Wisconsin, Madison*.

Peng, X., D. Chen, and L. Kong (2014). "A clipping dual coordinate descent algorithm for