

Hyperparameter Tuning Cookbook

A guide for scikit-learn, PyTorch, river, and spotPython

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Table of contents

Preface	3
Citation	3
1 Introduction: Hyperparameter Tuning	5
1.1 The Hyperparameter Tuning Software SPOT	6
1.2 Spot as an Optimizer	7
1.3 Example: <code>Spot</code> and the Sphere Function	8
1.3.1 The Objective Function: Sphere	8
1.4 Spot Parameters: <code>fun_evals</code> , <code>init_size</code> and <code>show_models</code>	10
1.5 Print the Results	12
1.6 Show the Progress	12
1.7 Visualizing the Hyperparameter Tuning Process with TensorBoard	13
2 Multi-dimensional Functions	16
2.1 Example: <code>Spot</code> and the 3-dim Sphere Function	16
2.1.1 The Objective Function: 3-dim Sphere	16
2.1.2 Results	18
2.1.3 A Contour Plot	18
2.1.4 TensorBoard	20
2.2 Conclusion	21
2.3 Exercises	22
2.3.1 The Three Dimensional <code>fun_cubed</code>	22
2.3.2 The Ten Dimensional <code>fun_wing_wt</code>	22
2.3.3 The Three Dimensional <code>fun_runge</code>	22
2.3.4 The Three Dimensional <code>fun_linear</code>	23
3 Isotropic and Anisotropic Kriging	24
3.1 Example: Isotropic <code>Spot</code> Surrogate and the 2-dim Sphere Function	24
3.1.1 The Objective Function: 2-dim Sphere	24
3.1.2 Results	25
3.2 Example With Anisotropic Kriging	25
3.2.1 Taking a Look at the <code>theta</code> Values	28
3.3 Exercises	29
3.3.1 <code>fun_branin</code>	29
3.3.2 <code>fun_sin_cos</code>	30

3.3.3	<code>fun_runge</code>	30
3.3.4	<code>fun_wingwt</code>	30
4	Using sklearn Surrogates in spotPython	31
4.1	Example: Branin Function with <code>spotPython</code> 's Internal Kriging Surrogate . . .	31
4.1.1	The Objective Function Branin	31
4.1.2	Running the surrogate model based optimizer <code>Spot</code> :	32
4.1.3	TensorBoard	32
4.1.4	Print the Results	34
4.1.5	Show the Progress and the Surrogate	34
4.2	Example: Using Surrogates From <code>scikit-learn</code>	35
4.2.1	GaussianProcessRegressor as a Surrogate	36
4.3	Example: One-dimensional Sphere Function With <code>spotPython</code> 's Kriging	37
4.3.1	Results	42
4.4	Example: <code>Sklearn</code> Model GaussianProcess	43
4.5	Exercises	49
4.5.1	<code>DecisionTreeRegressor</code>	49
4.5.2	<code>RandomForestRegressor</code>	50
4.5.3	<code>linear_model.LinearRegression</code>	50
4.5.4	<code>linear_model.Ridge</code>	50
4.6	Exercise 2	50
5	Sequential Parameter Optimization: Using <code>scipy</code> Optimizers	51
5.1	The Objective Function Branin	51
5.2	The Optimizer	52
5.2.1	TensorBoard	53
5.3	Print the Results	54
5.4	Show the Progress	55
5.5	Exercises	56
5.5.1	<code>dual_annealing</code>	56
5.5.2	<code>direct</code>	56
5.5.3	<code>shgo</code>	56
5.5.4	<code>basinhopping</code>	57
5.5.5	Performance Comparison	57
6	Sequential Parameter Optimization: Gaussian Process Models	58
6.1	Gaussian Processes Regression: Basic Introductory <code>scikit-learn</code> Example . .	58
6.1.1	Train and Test Data	59
6.1.2	Building the Surrogate With <code>Sklearn</code>	59
6.1.3	Plotting the <code>SklearnModel</code>	59
6.1.4	The <code>spotPython</code> Version	60
6.1.5	Visualizing the Differences Between the <code>spotPython</code> and the <code>sklearn</code> Model Fits	61

6.2	Exercises	62
6.2.1	Schonlau Example Function	62
6.2.2	Forrester Example Function	62
6.2.3	fun_runge Function (1-dim)	63
6.2.4	fun_cubed (1-dim)	64
6.2.5	The Effect of Noise	64
7	Expected Improvement	66
7.1	Example: <code>Spot</code> and the 1-dim Sphere Function	66
7.1.1	The Objective Function: 1-dim Sphere	66
7.1.2	Results	67
7.2	Same, but with EI as <code>infill_criterion</code>	68
7.3	Non-isotropic Kriging	69
7.4	Using <code>sklearn</code> Surrogates	72
7.4.1	The <code>spot</code> Loop	72
7.4.2	<code>spot</code> : The Initial Model	73
7.4.3	Init: Build Initial Design	74
7.4.4	Evaluate	76
7.4.5	Build Surrogate	76
7.4.6	A Simple Predictor	76
7.5	Gaussian Processes regression: basic introductory example	77
7.6	The Surrogate: Using <code>scikit-learn</code> models	80
7.7	Additional Examples	82
7.7.1	Optimize on Surrogate	85
7.7.2	Evaluate on Real Objective	85
7.7.3	Impute / Infill new Points	85
7.8	Tests	85
7.9	EI: The Famous Schonlau Example	86
7.10	EI: The Forrester Example	88
7.11	Noise	91
7.12	Cubic Function	94
7.13	Factors	100
8	Hyperparameter Tuning and Noise	102
8.1	Example: <code>Spot</code> and the Noisy Sphere Function	102
8.1.1	The Objective Function: Noisy Sphere	102
8.2	Print the Results	108
8.3	Noise and Surrogates: The Nugget Effect	109
8.3.1	The Noisy Sphere	109
8.4	Exercises	112
8.4.1	Noisy <code>fun_cubed</code>	112
8.4.2	<code>fun_runge</code>	113
8.4.3	<code>fun_forrester</code>	113

8.4.4	<code>fun_xsin</code>	113
9	Handling Noise: Optimal Computational Budget Allocation in Spot	114
9.1	Example: <code>Spot</code> , OCBA, and the Noisy Sphere Function	114
9.1.1	The Objective Function: Noisy Sphere	114
9.2	Print the Results	119
9.3	Noise and Surrogates: The Nugget Effect	120
9.3.1	The Noisy Sphere	120
9.4	Exercises	123
9.4.1	Noisy <code>fun_cubed</code>	123
9.4.2	<code>fun_runge</code>	123
9.4.3	<code>fun_forrester</code>	123
9.4.4	<code>fun_xsin</code>	124
10	HPT: sklearn SVC on Moons Data	125
10.1	Step 1: Setup	125
10.2	Step 2: Initialization of the Empty <code>fun_control</code> Dictionary	125
10.3	Step 3: SKlearn Load Data (Classification)	126
10.4	Step 4: Specification of the Preprocessing Model	128
10.5	Step 5: Select Model (<code>algorithm</code>) and <code>core_model_hyper_dict</code>	128
10.6	Step 6: Modify <code>hyper_dict</code> Hyperparameters for the Selected Algorithm aka <code>core_model</code>	131
10.6.1	Modify hyperparameter of type numeric and integer (boolean)	131
10.6.2	Modify hyperparameter of type factor	132
10.6.3	Optimizers	132
10.7	Step 7: Selection of the Objective (Loss) Function	132
10.7.1	Predict Classes or Class Probabilities	133
10.8	Step 8: Calling the SPOT Function	133
10.8.1	Preparing the SPOT Call	133
10.8.2	The Objective Function	134
10.8.3	Run the <code>Spot</code> Optimizer	134
10.8.4	Starting the Hyperparameter Tuning	135
10.9	Step 9: Results	136
10.9.1	Show variable importance	138
10.9.2	Get Default Hyperparameters	138
10.9.3	Get SPOT Results	139
10.9.4	Plot: Compare Predictions	140
10.9.5	Detailed Hyperparameter Plots	142
10.9.6	Parallel Coordinates Plot	143
10.9.7	Plot all Combinations of Hyperparameters	143
11	river Hyperparameter Tuning: HATR with Friedman Drift Data	144
11.1	Setup	144

11.2	Initialization of the Empty <code>fun_control</code> Dictionary	145
11.3	Load Data: The Friedman Drift Data	145
11.4	Specification of the Preprocessing Model	146
11.5	Select Select Model (<code>algorithm</code>) and <code>core_model_hyper_dict</code>	146
11.6	Modify <code>hyper_dict</code> Hyperparameters for the Selected Algorithm aka <code>core_model</code>	147
11.6.1	Modify hyperparameter of type factor	147
11.6.2	Modify hyperparameter of type numeric and integer (boolean)	147
11.7	Selection of the Objective (Loss) Function	147
11.8	Calling the SPOT Function	148
11.8.1	Prepare the SPOT Parameters	148
11.8.2	The Objective Function	149
11.8.3	Run the <code>Spot</code> Optimizer	149
11.8.4	TensorBoard	151
11.8.5	Results	151
11.9	Show variable importance	154
11.10	Build and Evaluate HTR Model with Tuned Hyperparameters	154
11.11	Der große Datensatz	155
11.12	Get Default Hyperparameters	156
11.13	Get SPOT Results	159
11.14	Visualize Regression Trees	163
11.14.1	Spot Model	163
11.15	Detailed Hyperparameter Plots	164
11.16	Parallel Coordinates Plots	165
11.17	Plot all Combinations of Hyperparameters	165
12	HPT: PyTorch With <code>spotPython</code> and Ray Tune on CIFAR10	166
12.1	Step 1: Setup	166
12.2	Step 2: Initialization of the <code>fun_control</code> Dictionary	167
12.3	Step 3: PyTorch Data Loading	168
12.4	Step 4: Specification of the Preprocessing Model	168
12.5	Step 5: Select Model (<code>algorithm</code>) and <code>core_model_hyper_dict</code>	169
12.5.1	The <code>Net_Core</code> class	171
12.5.2	Comparison of the Approach Described in the PyTorch Tutorial With <code>spotPython</code>	172
12.5.3	The Search Space: Hyperparameters	172
12.5.4	Configuring the Search Space With Ray Tune	172
12.5.5	Configuring the Search Space With <code>spotPython</code>	173
12.6	Step 6: Modify <code>hyper_dict</code> Hyperparameters for the Selected Algorithm aka <code>core_model</code>	175
12.6.1	Optimizers	177
12.7	Step 7: Selection of the Objective (Loss) Function	178
12.7.1	Evaluation: Data Splitting	178
12.7.2	Hold-out Data Split	178

12.7.3	Cross-Validation	179
12.7.4	Overview of the Evaluation Settings	180
12.7.5	Evaluation: Loss Functions and Metrics	181
12.8	Step 8: Calling the SPOT Function	182
12.8.1	Preparing the SPOT Call	182
12.8.2	The Objective Function <code>fun_torch</code>	183
12.8.3	Using Default Hyperparameters or Results from Previous Runs	183
12.8.4	Starting the Hyperparameter Tuning	183
12.9	Step 9: Tensorboard	190
12.9.1	Tensorboard: Start Tensorboard	190
12.9.2	Saving the State of the Notebook	190
12.10	Step 10: Results	192
12.10.1	Get the Tuned Architecture (SPOT Results)	194
12.10.2	Get Default Hyperparameters	195
12.10.3	Evaluation of the Default Architecture	195
12.10.4	Evaluation of the Tuned Architecture	197
12.10.5	Detailed Hyperparameter Plots	199
12.11	Summary and Outlook	201
12.12	Appendix	201
12.12.1	Sample Output From Ray Tune's Run	201

13 HPT: sklearn RandomForestClassifier VBDP Data 203

13.1	Step 1: Setup	203
13.2	Step 2: Initialization of the Empty <code>fun_control</code> Dictionary	204
13.3	Step 3: PyTorch Data Loading	204
13.3.1	Load Data: Classification VBDP	204
13.3.2	Holdout Train and Test Data	205
13.4	Step 4: Specification of the Preprocessing Model	206
13.5	Step 5: Select Model (<code>algorithm</code>) and <code>core_model_hyper_dict</code>	206
13.6	Step 6: Modify <code>hyper_dict</code> Hyperparameters for the Selected Algorithm aka <code>core_model</code>	208
13.6.1	Modify hyperparameter of type numeric and integer (boolean)	208
13.6.2	Modify hyperparameter of type factor	208
13.6.3	Optimizers	209
13.6.4	Selection of the Objective: Metric and Loss Functions	209
13.7	Step 7: Selection of the Objective (Loss) Function	209
13.7.1	Metric Function	209
13.7.2	Evaluation on Hold-out Data	211
13.7.3	OOB Score	211
13.8	Step 8: Calling the SPOT Function	212
13.8.1	Preparing the SPOT Call	212
13.8.2	The Objective Function	212
13.8.3	Run the Spot Optimizer	213

13.9	Step 9: Tensorboard	215
13.10	Step 10: Results	215
13.10.1	Show variable importance	217
13.10.2	Get Default Hyperparameters	217
13.10.3	Get SPOT Results	218
13.10.4	Evaluate SPOT Results	219
13.10.5	Handling Non-deterministic Results	220
13.10.6	Evaluation of the Default Hyperparameters	220
13.10.7	Plot: Compare Predictions	221
13.10.8	Cross-validated Evaluations	223
13.10.9	Detailed Hyperparameter Plots	224
13.10.10	Parallel Coordinates Plot	230
13.10.11	Plot all Combinations of Hyperparameters	230
14	HPT: sklearn XGB Classifier VBDP Data	231
14.1	Step 1: Setup	231
14.2	Step 2: Initialization of the Empty <code>fun_control</code> Dictionary	232
14.3	Step 3: PyTorch Data Loading	232
14.3.1	1. Load Data: Classification VBDP	232
14.3.2	Holdout Train and Test Data	233
14.4	Step 4: Specification of the Preprocessing Model	234
14.5	Step 5: Select Model (<code>algorithm</code>) and <code>core_model_hyper_dict</code>	234
14.6	Step 6: Modify <code>hyper_dict</code> Hyperparameters for the Selected Algorithm aka <code>core_model</code>	236
14.6.1	Modify hyperparameter of type numeric and integer (boolean)	236
14.6.2	Modify hyperparameter of type factor	236
14.6.3	Optimizers	237
14.7	Step 7: Selection of the Objective (Loss) Function	237
14.7.1	Evaluation	237
14.7.2	Selection of the Objective: Metric and Loss Functions	237
14.7.3	Loss Function	237
14.7.4	Metric Function	238
14.7.5	Evaluation on Hold-out Data	239
14.8	Step 8: Calling the SPOT Function	239
14.8.1	Preparing the SPOT Call	239
14.8.2	The Objective Function	240
14.8.3	Run the <code>Spot</code> Optimizer	240
14.9	Step 9: Tensorboard	242
14.10	Step 10: Results	242
14.10.1	Show variable importance	244
14.10.2	Get Default Hyperparameters	244
14.10.3	Get SPOT Results	245
14.10.4	Evaluate SPOT Results	246

14.10.5	Handling Non-deterministic Results	247
14.10.6	Evaluation of the Default Hyperparameters	247
14.10.7	Plot: Compare Predictions	248
14.10.8	Cross-validated Evaluations	250
14.10.9	Detailed Hyperparameter Plots	251
14.10.10	Parallel Coordinates Plot	252
14.10.11	Plot all Combinations of Hyperparameters	252
15	HPT: sklearn SVC VBDP Data	254
15.1	Step 1: Setup	254
15.2	Step 2: Initialization of the Empty <code>fun_control</code> Dictionary	255
15.3	Step 3: PyTorch Data Loading	255
15.3.1	1. Load Data: Classification VBDP	255
15.3.2	Holdout Train and Test Data	256
15.4	Step 4: Specification of the Preprocessing Model	257
15.5	Step 5: Select Model (<code>algorithm</code>) and <code>core_model_hyper_dict</code>	257
15.6	Step 6: Modify <code>hyper_dict</code> Hyperparameters for the Selected Algorithm aka <code>core_model</code>	259
15.6.1	Modify hyperparameter of type numeric and integer (boolean)	259
15.6.2	Modify hyperparameter of type factor	259
15.6.3	Optimizers	260
15.6.4	Selection of the Objective: Metric and Loss Functions	260
15.7	Step 7: Selection of the Objective (Loss) Function	260
15.7.1	Metric Function	260
15.7.2	Evaluation on Hold-out Data	261
15.8	Step 8: Calling the SPOT Function	262
15.8.1	Preparing the SPOT Call	262
15.8.2	The Objective Function	263
15.8.3	Run the <code>Spot</code> Optimizer	263
15.9	Step 9: Tensorboard	267
15.10	Step 10: Results	267
15.10.1	Show variable importance	269
15.10.2	Get Default Hyperparameters	269
15.10.3	Get SPOT Results	270
15.10.4	Evaluate SPOT Results	271
15.10.5	Handling Non-deterministic Results	272
15.10.6	Evaluation of the Default Hyperparameters	272
15.10.7	Plot: Compare Predictions	273
15.10.8	Cross-validated Evaluations	275
15.10.9	Detailed Hyperparameter Plots	276
15.10.10	Parallel Coordinates Plot	279
15.10.11	Plot all Combinations of Hyperparameters	279

16 HPT: sklearn KNN Classifier VBDP Data	280
16.1 Step 1: Setup	280
16.2 Step 2: Initialization of the Empty <code>fun_control</code> Dictionary	281
16.2.1 Load Data: Classification VBDP	281
16.2.2 Holdout Train and Test Data	282
16.3 Step 4: Specification of the Preprocessing Model	283
16.4 Step 5: Select Model (<code>algorithm</code>) and <code>core_model_hyper_dict</code>	283
16.5 Step 6: Modify <code>hyper_dict</code> Hyperparameters for the Selected Algorithm aka <code>core_model</code>	285
16.5.1 Modify hyperparameter of type numeric and integer (boolean)	285
16.5.2 Modify hyperparameter of type factor	285
16.5.3 Optimizers	286
16.5.4 Selection of the Objective: Metric and Loss Functions	286
16.6 Step 7: Selection of the Objective (Loss) Function	286
16.6.1 Metric Function	286
16.6.2 Evaluation on Hold-out Data	287
16.7 Step 8: Calling the SPOT Function	288
16.7.1 Preparing the SPOT Call	288
16.7.2 The Objective Function	288
16.7.3 Run the <code>Spot</code> Optimizer	289
16.8 Step 9: Tensorboard	293
16.9 Step 10: Results	293
16.9.1 Show variable importance	294
16.9.2 Get Default Hyperparameters	294
16.9.3 Get SPOT Results	295
16.9.4 Evaluate SPOT Results	295
16.9.5 Handling Non-deterministic Results	296
16.9.6 Evaluation of the Default Hyperparameters	297
16.9.7 Plot: Compare Predictions	297
16.9.8 Cross-validated Evaluations	299
16.9.9 Detailed Hyperparameter Plots	300
16.9.10 Parallel Coordinates Plot	301
16.9.11 Plot all Combinations of Hyperparameters	301
 17 HPT PyTorch Lightning: VBDP	 303
17.1 Step 1: Setup	303
17.2 Step 2: Initialization of the <code>fun_control</code> Dictionary	304
17.3 Step 3: PyTorch Data Loading	305
17.3.1 Lightning Dataset and DataModule	305
17.4 Step 4: Preprocessing	305
17.5 Step 5: Select the NN Model (<code>algorithm</code>) and <code>core_model_hyper_dict</code>	305
17.6 Step 6: Modify <code>hyper_dict</code> Hyperparameters for the Selected Algorithm aka <code>core_model</code>	306

17.7	Step 7: Data Splitting, the Objective (Loss) Function and the Metric	307
17.7.1	Evaluation	307
17.7.2	Loss Functions and Metrics	307
17.7.3	Metric	307
17.8	Step 8: Calling the SPOT Function	308
17.8.1	Preparing the SPOT Call	308
17.8.2	The Objective Function <code>fun</code>	308
17.8.3	Starting the Hyperparameter Tuning	308
17.9	Step 9: Tensorboard	312
17.10	Step 10: Results	312
17.10.1	Get the Tuned Architecture	314
17.10.2	Cross Validation With Lightning	315
17.10.3	Detailed Hyperparameter Plots	319
17.10.4	Parallel Coordinates Plot	320
17.10.5	Plot all Combinations of Hyperparameters	321
17.10.6	Visualizing the Activation Distribution	321
17.11	Submission	323
17.12	Appendix	327
17.12.1	Differences to the <code>spotPython</code> Approaches for <code>torch</code> , <code>sklearn</code> and <code>river</code>	327
17.12.2	Taking a Look at the Data	327
17.12.3	The MAPK Metric	328
18	Documentation of the Sequential Parameter Optimization	330
18.1	Example: <code>spot</code>	330
18.1.1	The Objective Function	330
18.1.2	External Parameters	332
18.2	The <code>fun_control</code> Dictionary	335
18.3	The <code>design_control</code> Dictionary	335
18.4	The <code>surrogate_control</code> Dictionary	336
18.5	The <code>optimizer_control</code> Dictionary	336
18.6	Run	337
18.7	Print the Results	339
18.8	Show the Progress	339
18.9	Visualize the Surrogate	339
18.10	Init: Build Initial Design	340
18.11	Replicability	341
18.12	Surrogates	342
18.12.1	A Simple Predictor	342
18.13	Demo/Test: Objective Function Fails	342
18.14	PyTorch: Detailed Description of the Data Splitting	345
18.14.1	Description of the " <code>train_hold_out</code> " Setting	345
	References	356

Preface

The goal of hyperparameter tuning (or hyperparameter optimization) is to optimize the hyperparameters to improve the performance of the machine or deep learning model.

spotPython (“Sequential Parameter Optimization Toolbox in Python”) is the Python version of the well-known hyperparameter tuner SPOT, which has been developed in the R programming environment for statistical analysis for over a decade. The related open-access book is available here: [Hyperparameter Tuning for Machine and Deep Learning with R—A Practical Guide](#).

[scikit-learn](#) is a Python module for machine learning built on top of SciPy and is distributed under the 3-Clause BSD license. The project was started in 2007 by David Cournapeau as a Google Summer of Code project, and since then many volunteers have contributed.

[PyTorch](#) is an optimized tensor library for deep learning using GPUs and CPUs.

[River](#) is a Python library for online machine learning. It is designed to be used in real-world environments, where not all data is available at once, but streaming in.

! Important: This book is still under development.

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1 Introduction: Hyperparameter Tuning

Hyperparameter tuning is an important, but often difficult and computationally intensive task. Changing the architecture of a neural network or the learning rate of an optimizer can have a significant impact on the performance.

The goal of hyperparameter tuning is to optimize the hyperparameters in a way that improves the performance of the machine learning or deep learning model. The simplest, but also most computationally expensive, approach uses manual search (or trial-and-error (Meignan et al. 2015)). Commonly encountered is simple random search, i.e., random and repeated selection of hyperparameters for evaluation, and lattice search (“grid search”). In addition, methods that perform directed search and other model-free algorithms, i.e., algorithms that do not explicitly rely on a model, e.g., evolution strategies (Bartz-Beielstein et al. 2014) or pattern search (Lewis, Torczon, and Trosset 2000) play an important role. Also, “hyperband”, i.e., a multi-armed bandit strategy that dynamically allocates resources to a set of random configurations and uses successive bisections to stop configurations with poor performance (Li et al. 2016), is very common in hyperparameter tuning. The most sophisticated and efficient approaches are the Bayesian optimization and surrogate model based optimization methods, which are based on the optimization of cost functions determined by simulations or experiments.

We consider below a surrogate model based optimization-based hyperparameter tuning approach based on the Python version of the SPOT (“Sequential Parameter Optimization Toolbox”) (Bartz-Beielstein, Lasarczyk, and Preuss 2005), which is suitable for situations where only limited resources are available. This may be due to limited availability and cost of hardware, or due to the fact that confidential data may only be processed locally, e.g., due to legal requirements. Furthermore, in our approach, the understanding of algorithms is seen as a key tool for enabling transparency and explainability. This can be enabled, for example, by quantifying the contribution of machine learning and deep learning components (nodes, layers, split decisions, activation functions, etc.). Understanding the importance of hyperparameters and the interactions between multiple hyperparameters plays a major role in the interpretability and explainability of machine learning models. SPOT provides statistical tools for understanding hyperparameters and their interactions. Last but not least, it should be noted that the SPOT software code is available in the open source `spotPython` package on github¹, allowing replicability of the results. This tutorial describes the Python variant of SPOT, which is called

¹<https://github.com/sequential-parameter-optimization>

`spotPython`. The R implementation is described in Bartz et al. (2022). SPOT is an established open source software that has been maintained for more than 15 years (Bartz-Beielstein, Lasarczyk, and Preuss 2005) (Bartz et al. 2022).

This document is structured as follows. The concept of the hyperparameter tuning software `spotPython` is described in Section 1.1. Chapter 12 describes the execution of the example from the tutorial “Hyperparameter Tuning with Ray Tune” (PyTorch 2023a). The integration of `spotPython` into the PyTorch training workflow is described in detail in the following sections. Section 12.1 describes the setup of the tuners. Section 12.3 describes the data loading. Section 12.5 describes the model to be tuned. The search space is introduced in Section 12.5.3. Optimizers are presented in Section 12.6.1. How to split the data in train, validation, and test sets is described in Section 12.7.1. The selection of the loss function and metrics is described in Section 12.7.5. Section 12.8.1 describes the preparation of the `spotPython` call. The objective function is described in Section 12.8.2. How to use results from previous runs and default hyperparameter configurations is described in Section 12.8.3. Starting the tuner is shown in Section 12.8.4. TensorBoard can be used to visualize the results as shown in Section 12.9. Results are discussed and explained in Section 12.10.

Chapter 17 shows the integration of `spotPython` into the PyTorch Lightning training workflow.

Section 12.11 presents a summary and an outlook.

i Note

The corresponding `.ipynb` notebook (Bartz-Beielstein 2023) is updated regularly and reflects updates and changes in the `spotPython` package. It can be downloaded from https://github.com/sequential-parameter-optimization/spotPython/blob/main/notebooks/14_spot_ray_hpt_torch_cifar10.ipynb.

1.1 The Hyperparameter Tuning Software SPOT

Surrogate model based optimization methods are common approaches in simulation and optimization. SPOT was developed because there is a great need for sound statistical analysis of simulation and optimization algorithms. SPOT includes methods for tuning based on classical regression and analysis of variance techniques. It presents tree-based models such as classification and regression trees and random forests as well as Bayesian optimization (Gaussian process models, also known as Kriging). Combinations of different meta-modeling approaches are possible. SPOT comes with a sophisticated surrogate model based optimization method, that can handle discrete and continuous inputs. Furthermore, any model implemented in `scikit-learn` can be used out-of-the-box as a surrogate in `spotPython`.

SPOT implements key techniques such as exploratory fitness landscape analysis and sensitivity analysis. It can be used to understand the performance of various algorithms, while simultaneously giving insights into their algorithmic behavior. In addition, SPOT can be used as an optimizer and for automatic and interactive tuning. Details on SPOT and its use in practice are given by Bartz et al. (2022).

A typical hyperparameter tuning process with `spotPython` consists of the following steps:

1. Loading the data (training and test datasets), see Section 12.3.
2. Specification of the preprocessing model, see Section 12.4. This model is called `prep_model` (“preparation” or pre-processing). The information required for the hyperparameter tuning is stored in the dictionary `fun_control`. Thus, the information needed for the execution of the hyperparameter tuning is available in a readable form.
3. Selection of the machine learning or deep learning model to be tuned, see Section 12.5. This is called the `core_model`. Once the `core_model` is defined, then the associated hyperparameters are stored in the `fun_control` dictionary. First, the hyperparameters of the `core_model` are initialized with the default values of the `core_model`. As default values we use the default values contained in the `spotPython` package for the algorithms of the `torch` package.
4. Modification of the default values for the hyperparameters used in `core_model`, see Section 12.6.0.1. This step is optional.
 1. numeric parameters are modified by changing the bounds.
 2. categorical parameters are modified by changing the categories (“levels”).
5. Selection of target function (loss function) for the optimizer, see Section 12.7.5.
6. Calling SPOT with the corresponding parameters, see Section 12.8.4. The results are stored in a dictionary and are available for further analysis.
7. Presentation, visualization and interpretation of the results, see Section 12.10.

1.2 Spot as an Optimizer

The `spot` loop consists of the following steps:

1. Init: Build initial design X
2. Evaluate initial design on real objective f : $y = f(X)$
3. Build surrogate: $S = S(X, y)$
4. Optimize on surrogate: $X_0 = \text{optimize}(S)$
5. Evaluate on real objective: $y_0 = f(X_0)$
6. Impute (Infill) new points: $X = X \cup X_0$, $y = y \cup y_0$.
7. Got 3.

Central Idea: Evaluation of the surrogate model S is much cheaper (or / and much faster) than running the real-world experiment f . We start with a small example.

1.3 Example: Spot and the Sphere Function

```
import numpy as np
from math import inf
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
from scipy.optimize import shgo
from scipy.optimize import direct
from scipy.optimize import differential_evolution
import matplotlib.pyplot as plt
```

1.3.1 The Objective Function: Sphere

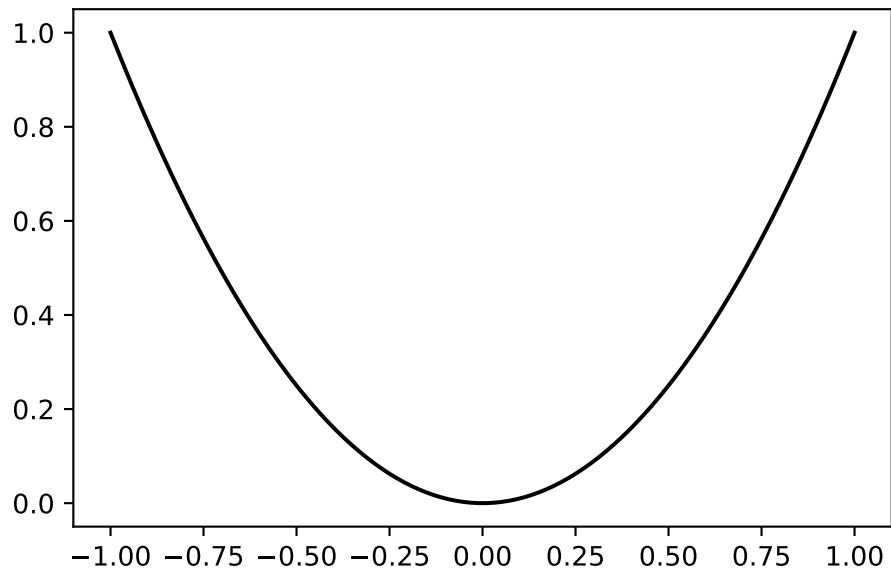
The `spotPython` package provides several classes of objective functions. We will use an analytical objective function, i.e., a function that can be described by a (closed) formula:

$$f(x) = x^2$$

```
fun = analytical().fun_sphere
```

We can apply the function `fun` to input values and plot the result:

```
x = np.linspace(-1,1,100).reshape(-1,1)
y = fun(x)
plt.figure()
plt.plot(x, y, "k")
plt.show()
```



```
spot_0 = spot.Spot(fun=fun,  
                  lower = np.array([-1]),  
                  upper = np.array([1]))
```

```
spot_0.run()
```

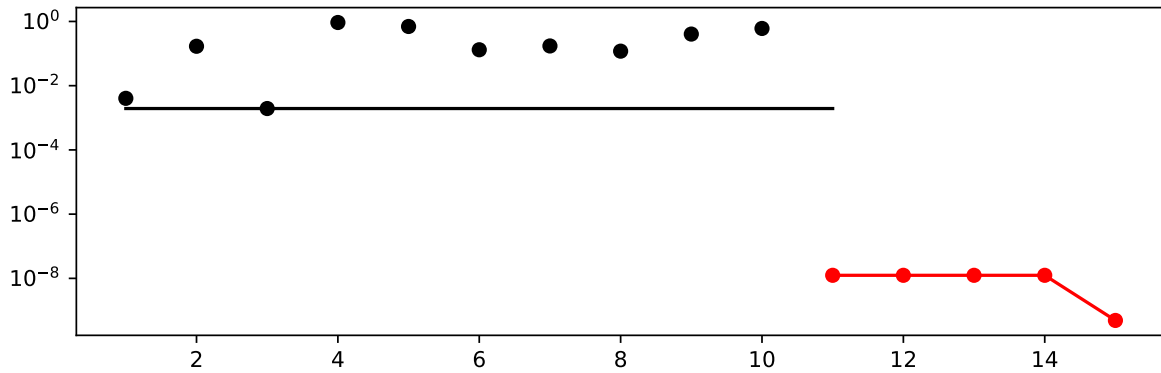
```
<spotPython.spot.spot.Spot at 0x1492f6950>
```

```
spot_0.print_results()
```

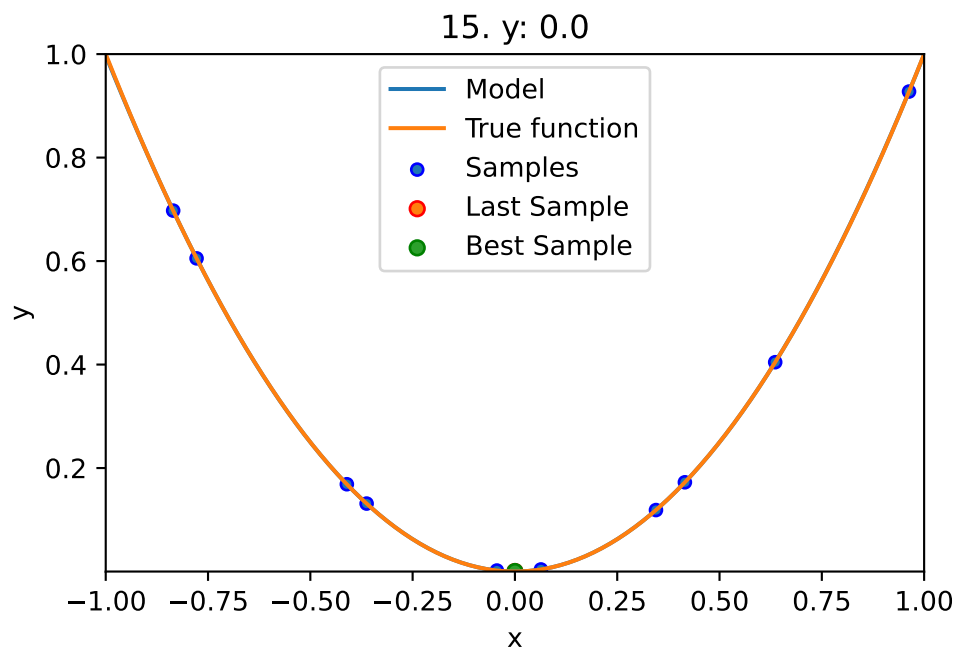
```
min y: 4.897545259852824e-10  
x0: 2.2130398233770724e-05
```

```
[['x0', 2.2130398233770724e-05]]
```

```
spot_0.plot_progress(log_y=True)
```



```
spot_0.plot_model()
```



1.4 Spot Parameters: fun_evals, init_size and show_models

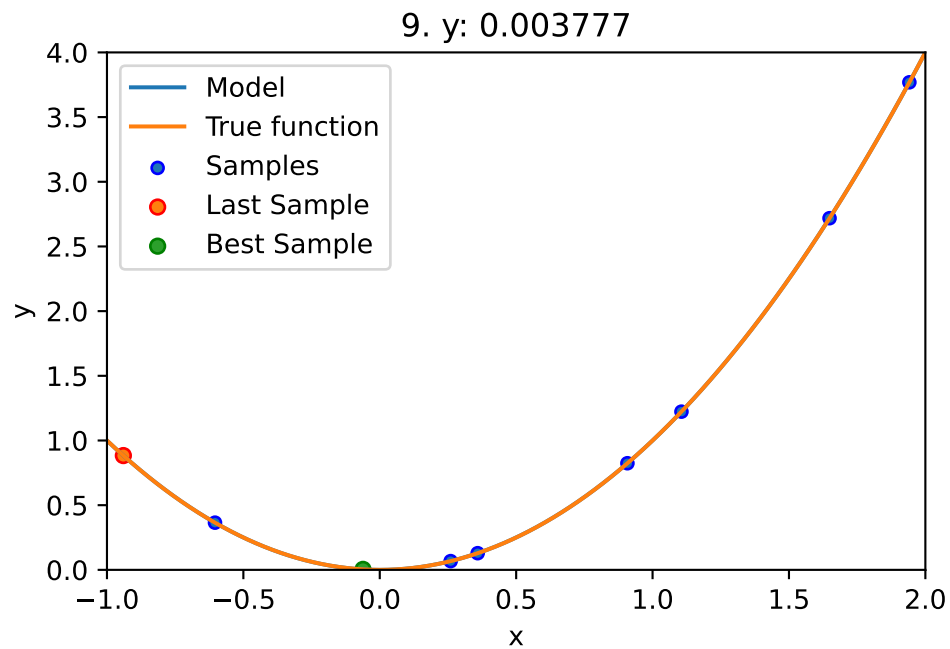
We will modify three parameters:

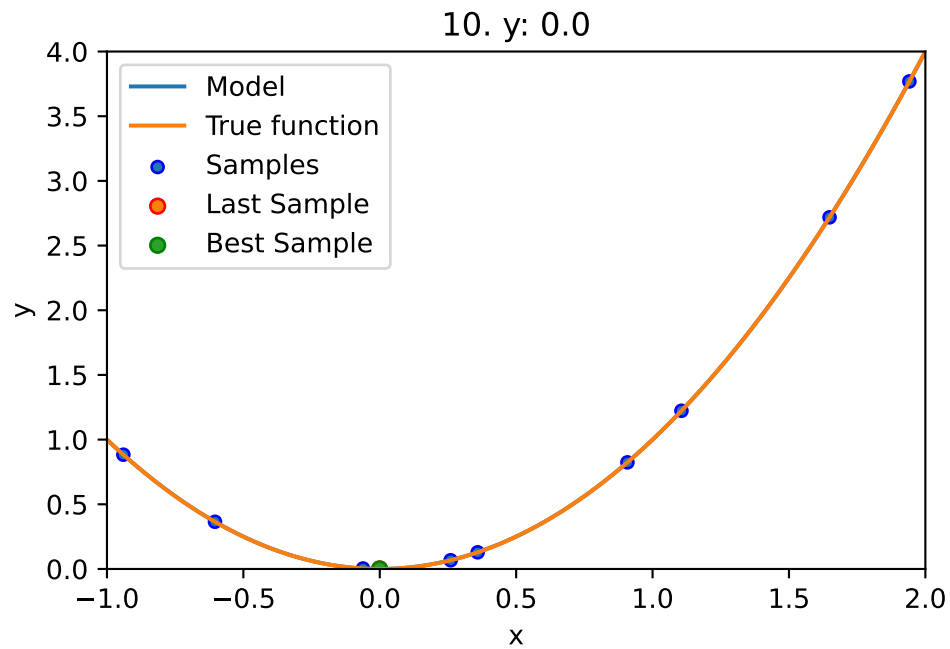
1. The number of function evaluations (`fun_evals`)
2. The size of the initial design (`init_size`)

3. The parameter `show_models`, which visualizes the search process for 1-dim functions.

The full list of the `Spot` parameters is shown in the Help System and in the notebook `spot_doc.ipynb`.

```
spot_1 = spot.Spot(fun=fun,  
                  lower = np.array([-1]),  
                  upper = np.array([2]),  
                  fun_evals= 10,  
                  seed=123,  
                  show_models=True,  
                  design_control={"init_size": 9})  
  
spot_1.run()
```





<spotPython.spot.spot.Spot at 0x149f7b8e0>

1.5 Print the Results

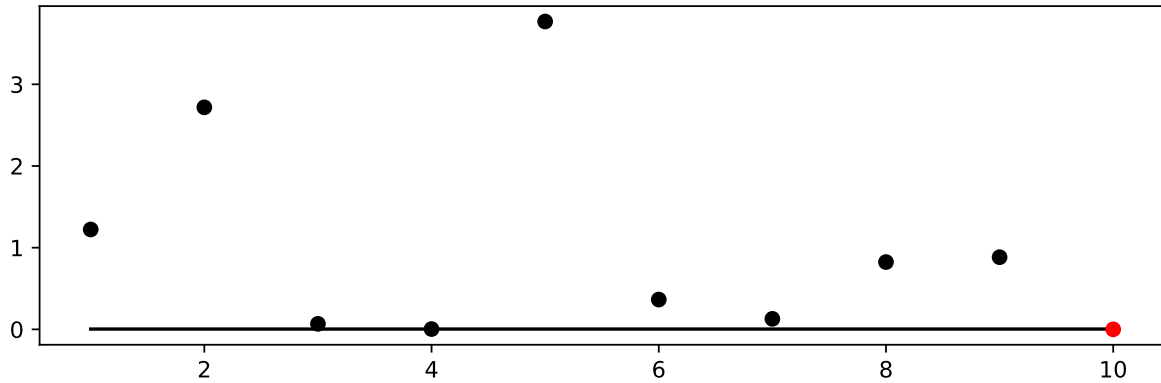
```
spot_1.print_results()
```

```
min y: 3.648984784366253e-07  
x0: -0.0006040682729929005
```

```
[['x0', -0.0006040682729929005]]
```

1.6 Show the Progress

```
spot_1.plot_progress()
```



1.7 Visualizing the Hyperparameter Tuning Process with TensorBoard

`spotPython` supports the visualization of the hyperparameter tuning process with TensorBoard. The following example shows how to use TensorBoard with `spotPython`.

First, we define an “experiment name” to identify the hyperparameter tuning process. The experiment name is used to create a directory for the TensorBoard files.

```
from spotPython.utils.file import get_experiment_name
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_spot_tensorboard_path

PREFIX = "01"
experiment_name = get_experiment_name(prefix=PREFIX)
print(experiment_name)

fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name))
```

01_bartz08-2_2023-07-10_00-19-18

Since the `spot_tensorboard_path` is defined, `spotPython` will log the optimization process in the TensorBoard files. The TensorBoard files are stored in the directory `spot_tensorboard_path`. We can pass the TensorBoard information to the `Spot` method via the `fun_control` dictionary.

```
spot_tuner = spot.Spot(fun=fun,
                        lower = np.array([-1]),
                        upper = np.array([2]),
                        fun_evals= 10,
                        seed=123,
                        show_models=False,
                        design_control={"init_size": 5},
                        fun_control=fun_control,)

spot_tuner.run()
```

```
<spotPython.spot.spot.Spot at 0x2c3d3fe50>
```

Now we can start TensorBoard in the background. The TensorBoard process will read the TensorBoard files and visualize the hyperparameter tuning process. From the terminal, we can start TensorBoard with the following command:

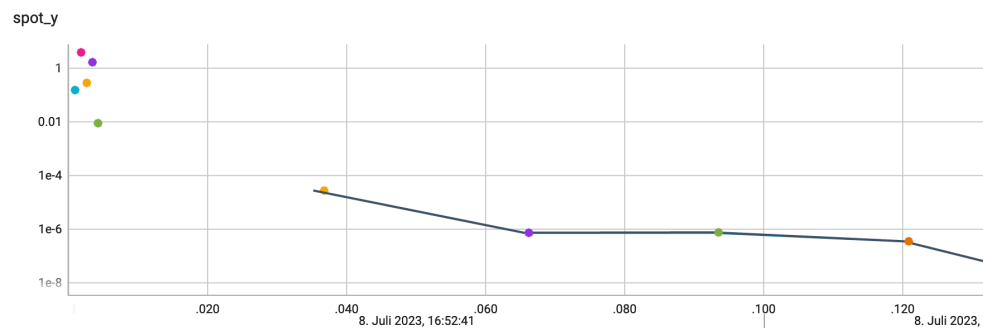
```
tensorboard --logdir="./runs"
```

`logdir` is the directory where the TensorBoard files are stored. In our case, the TensorBoard files are stored in the directory `./runs`.

TensorBoard will start a web server on port 6006. We can access the TensorBoard web server with the following URL:

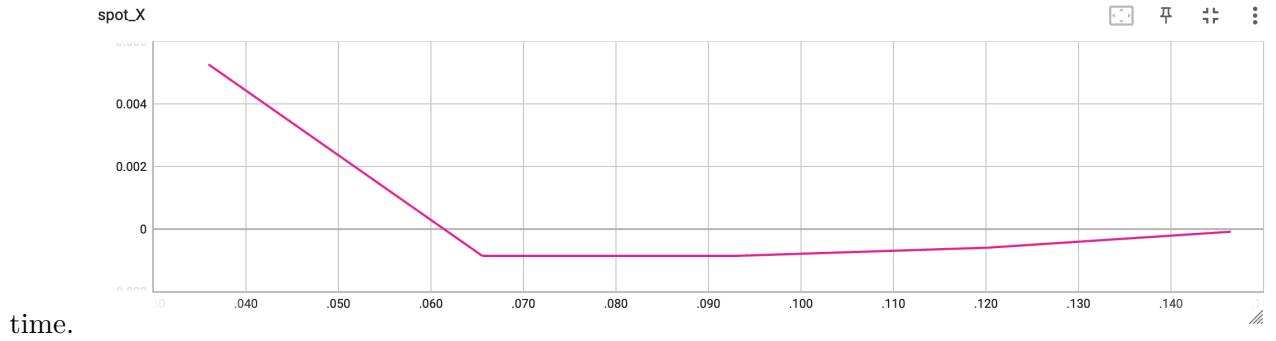
```
http://localhost:6006/
```

The first TensorBoard visualization shows the objective function values plotted against the wall time. The wall time is the time that has passed since the start of the hyperparameter tuning process. The five initial design points are shown in the upper left region of the plot. The line vi-



sualizes the optimization process.

The second TensorBoard visualization shows the input values, i.e., x_0 , plotted against the wall



time. The third TensorBoard plot illustrates how `spotPython` can be used as a microscope for the internal mechanisms of the surrogate-based optimization process. Here, one important parameter, the learning rate θ of the Kriging surrogate is plotted against the number of optimization steps.

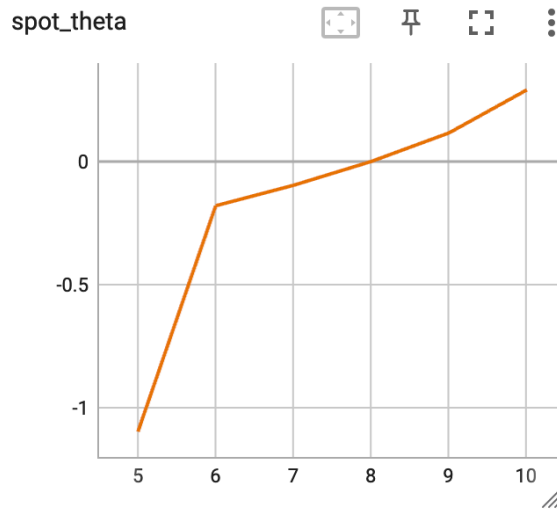


Figure 1.1: TensorBoard visualization of the `spotPython` process.

2 Multi-dimensional Functions

This notebook illustrates how high-dimensional functions can be analyzed.

2.1 Example: Spot and the 3-dim Sphere Function

```
import numpy as np
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
```

2.1.1 The Objective Function: 3-dim Sphere

- The `spotPython` package provides several classes of objective functions.
- We will use an analytical objective function, i.e., a function that can be described by a (closed) formula:

$$f(x) = \sum_i^n x_i^2$$

- Here we will use $n = 3$.

```
fun = analytical().fun_sphere
```

- The size of the `lower` bound vector determines the problem dimension.
- Here we will use `-1.0 * np.ones(3)`, i.e., a three-dim function.
- We will use three different `theta` values (one for each dimension), i.e., we set `surrogate_control={"n_theta": 3}`.

i TensorBoard

Similar to the one-dimensional case, which was introduced in Section [1.7](#), we can use TensorBoard to monitor the progress of the optimization. We will use the same code,

only the prefix is different:

```
from spotPython.utils.file import get_experiment_name
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_spot_tensorboard_path

PREFIX = "02"
experiment_name = get_experiment_name(prefix=PREFIX)
print(experiment_name)

fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name))
```

02_bartz08-2_2023-07-10_00-19-38

```
spot_3 = spot.Spot(fun=fun,
                    lower = -1.0*np.ones(3),
                    upper = np.ones(3),
                    var_name=["Pressure", "Temp", "Lambda"],
                    show_progress=True,
                    surrogate_control={"n_theta": 3},
                    fun_control=fun_control,)

spot_3.run()
```

spotPython tuning: 0.03443367156190887 [#####---] 73.33%

spotPython tuning: 0.031348911082058686 [#####--] 80.00%

spotPython tuning: 0.0009629115535977041 [#####-] 86.67%

spotPython tuning: 8.600065786394651e-05 [#####-] 93.33%

spotPython tuning: 5.9908343748136085e-05 [#####] 100.00% Done...

<spotPython.spot.spot.Spot at 0x16c8a22c0>

Now we can start TensorBoard in the background with the following command:

```
tensorboard --logdir="./runs"
```

We can access the TensorBoard web server with the following URL:

```
http://localhost:6006/
```

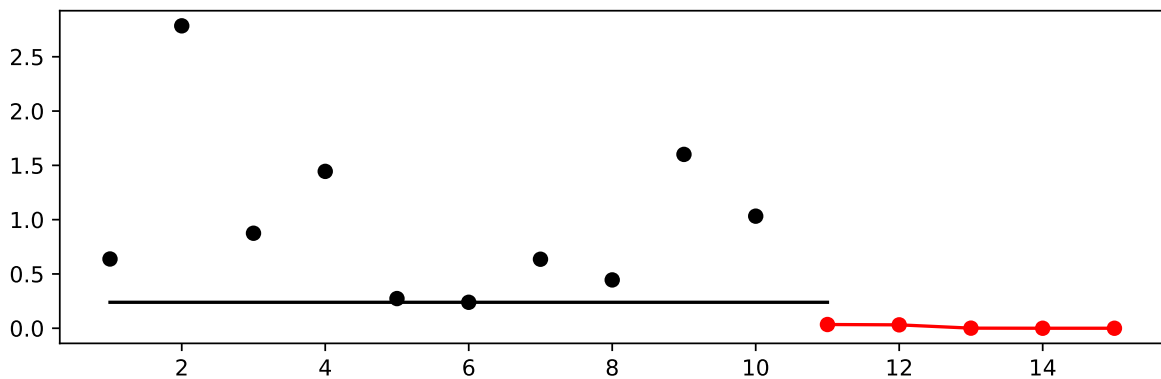
2.1.2 Results

```
spot_3.print_results()
```

```
min y: 5.9908343748136085e-05  
Pressure: 0.005157864627379999  
Temp: 0.00195710957248863  
Lambda: 0.005429042121316765
```

```
[['Pressure', 0.005157864627379999],  
 ['Temp', 0.00195710957248863],  
 ['Lambda', 0.005429042121316765]]
```

```
spot_3.plot_progress()
```

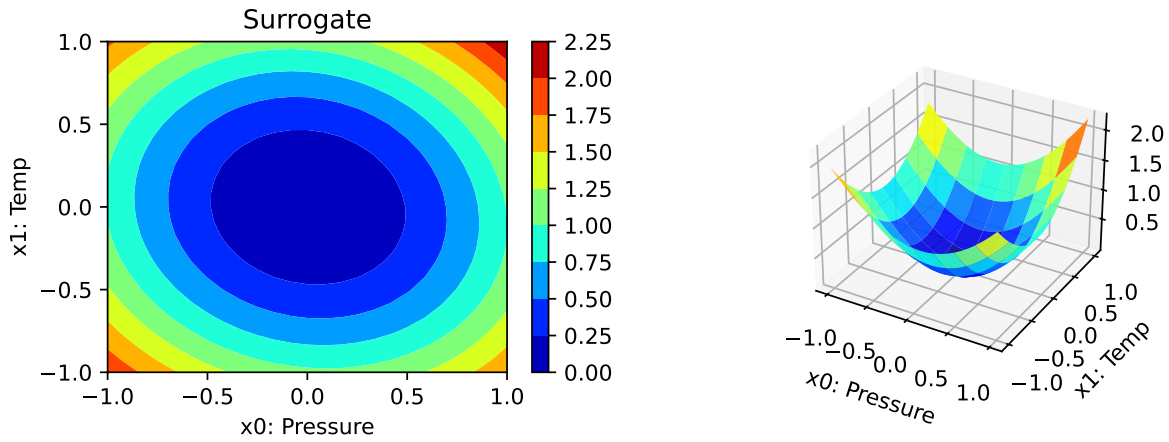


2.1.3 A Contour Plot

- We can select two dimensions, say $i = 0$ and $j = 1$, and generate a contour plot as follows.

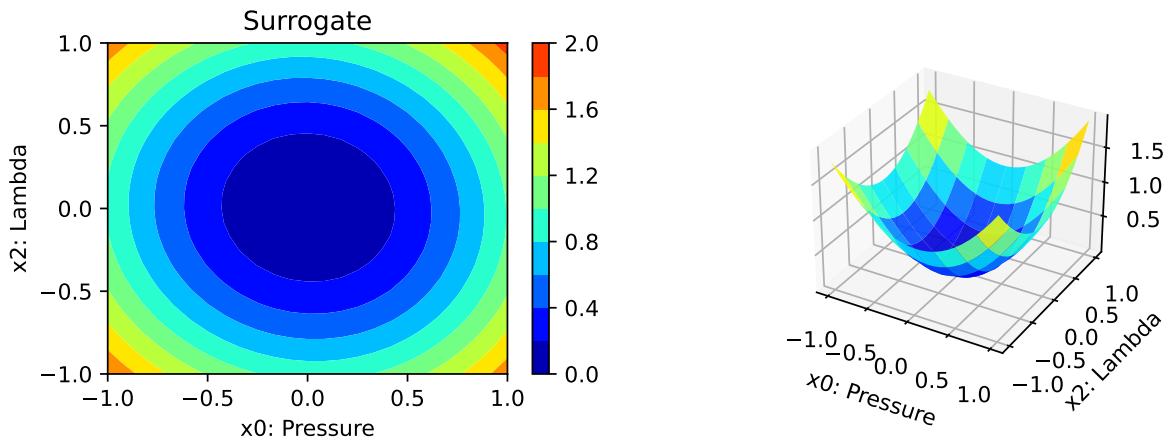
- Note: We have specified identical `min_z` and `max_z` values to generate comparable plots!

```
spot_3.plot_contour(i=0, j=1, min_z=0, max_z=2.25)
```



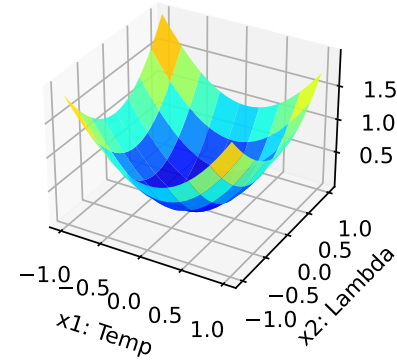
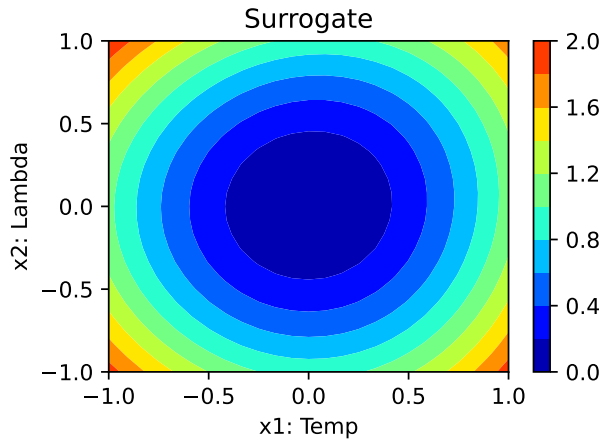
- In a similar manner, we can plot dimension $i = 0$ and $j = 2$:

```
spot_3.plot_contour(i=0, j=2, min_z=0, max_z=2.25)
```



- The final combination is $i = 1$ and $j = 2$:

```
spot_3.plot_contour(i=1, j=2, min_z=0, max_z=2.25)
```



- The three plots look very similar, because the `fun_sphere` is symmetric.
- This can also be seen from the variable importance:

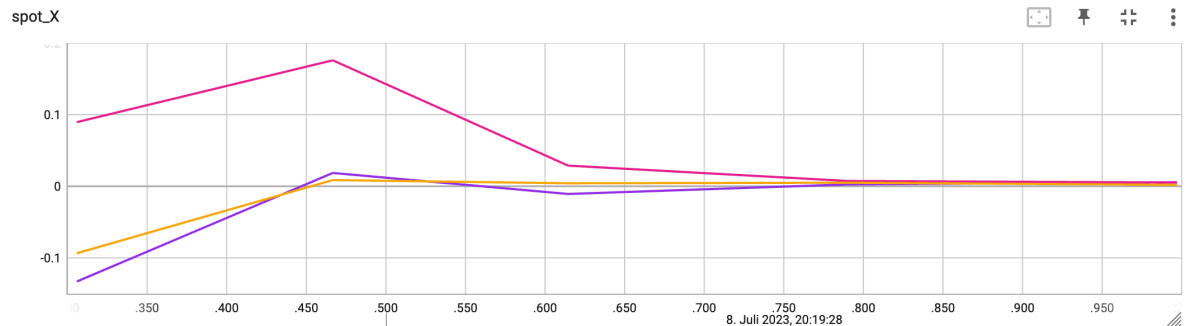
```
spot_3.print_importance()
```

```
Pressure: 100.0
Temp: 99.78247670817808
Lambda: 94.72233826625329
```

```
[['Pressure', 100.0],
 ['Temp', 99.78247670817808],
 ['Lambda', 94.72233826625329]]
```

2.1.4 TensorBoard

The second TensorBoard visualization shows the input values, i.e., x_0, \dots, x_2 , plotted against



the wall time.

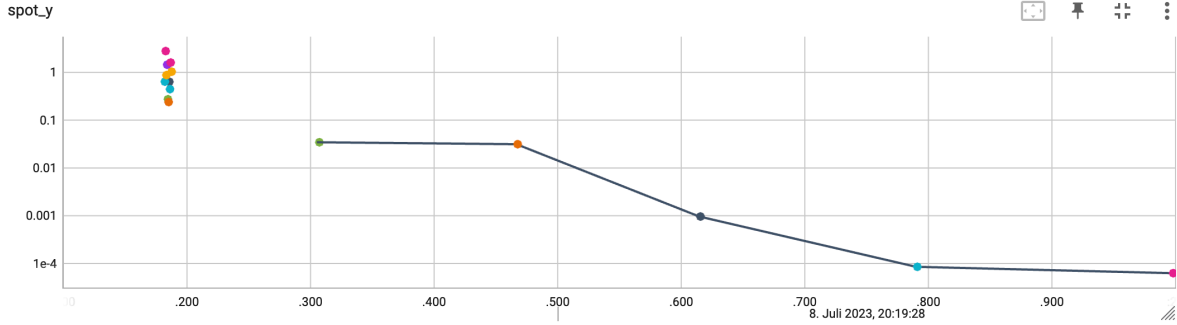


Figure 2.1: TensorBoard visualization of the spotPython process. Objective function values plotted against wall time.

The third TensorBoard plot illustrates how `spotPython` can be used as a microscope for the internal mechanisms of the surrogate-based optimization process. Here, one important parameter, the learning rate θ of the Kriging surrogate is plotted against the number of optimization steps.

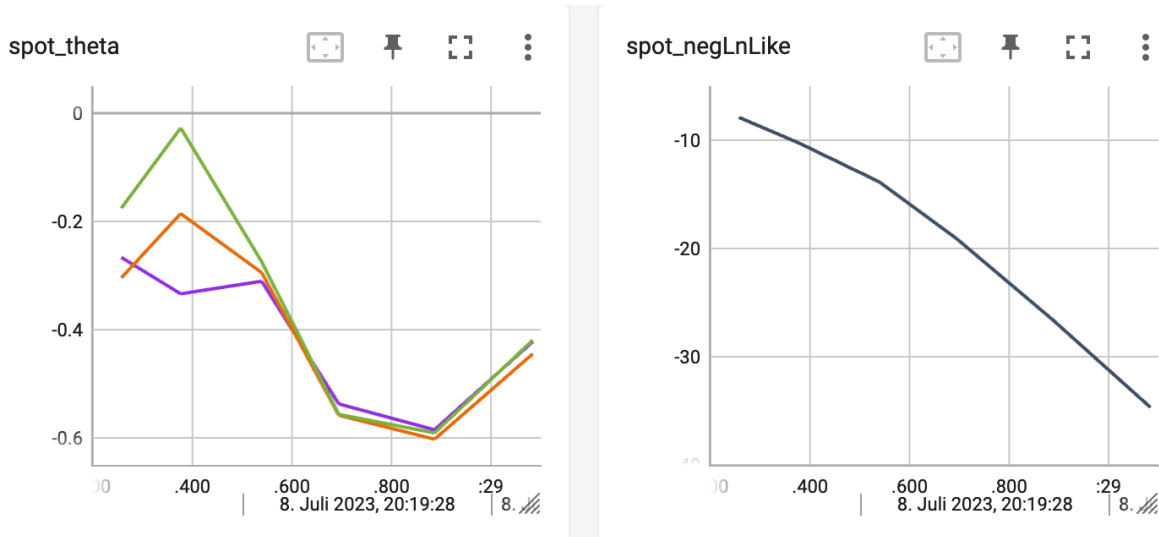


Figure 2.2: TensorBoard visualization of the spotPython surrogate model.

2.2 Conclusion

Based on this quick analysis, we can conclude that all three dimensions are equally important (as expected, because the analytical function is known).

2.3 Exercises

- Important:
 - Results from these exercises should be added to this document, i.e., you should submit an updated version of this notebook.
 - Please combine your results using this notebook.
 - Only one notebook from each group!
 - Presentation is based on this notebook. No additional slides are required!
 - spotPython version 0.16.11 (or greater) is required

2.3.1 The Three Dimensional `fun_cubed`

- The input dimension is 3. The search range is $-1 \leq x \leq 1$ for all dimensions.
- Generate contour plots
- Calculate the variable importance.
- Discuss the variable importance:
 - Are all variables equally important?
 - If not:
 - * Which is the most important variable?
 - * Which is the least important variable?

2.3.2 The Ten Dimensional `fun_wing_wt`

- The input dimension is 10. The search range is $0 \leq x \leq 1$ for all dimensions.
- Calculate the variable importance.
- Discuss the variable importance:
 - Are all variables equally important?
 - If not:
 - * Which is the most important variable?
 - * Which is the least important variable?
 - Generate contour plots for the three most important variables. Do they confirm your selection?

2.3.3 The Three Dimensional `fun_runge`

- The input dimension is 3. The search range is $-5 \leq x \leq 5$ for all dimensions.
- Generate contour plots
- Calculate the variable importance.

- Discuss the variable importance:
 - Are all variables equally important?
 - If not:
 - * Which is the most important variable?
 - * Which is the least important variable?

2.3.4 The Three Dimensional `fun_linear`

- The input dimension is 3. The search range is $-5 \leq x \leq 5$ for all dimensions.
- Generate contour plots
- Calculate the variable importance.
- Discuss the variable importance:
 - Are all variables equally important?
 - If not:
 - * Which is the most important variable?
 - * Which is the least important variable?

3 Isotropic and Anisotropic Kriging

3.1 Example: Isotropic Spot Surrogate and the 2-dim Sphere Function

```
import numpy as np
from math import inf
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
```

3.1.1 The Objective Function: 2-dim Sphere

- The `spotPython` package provides several classes of objective functions.
- We will use an analytical objective function, i.e., a function that can be described by a (closed) formula:

$$f(x, y) = x^2 + y^2$$

```
fun = analytical().fun_sphere
fun_control = {"sigma": 0,
               "seed": 123}
```

- The size of the `lower` bound vector determines the problem dimension.
- Here we will use `np.array([-1, -1])`, i.e., a two-dim function.

```
spot_2 = spot.Spot(fun=fun,
                   lower = np.array([-1, -1]),
                   upper = np.array([1, 1]))

spot_2.run()
```

```
<spotPython.spot.spot.Spot at 0x137a12860>
```

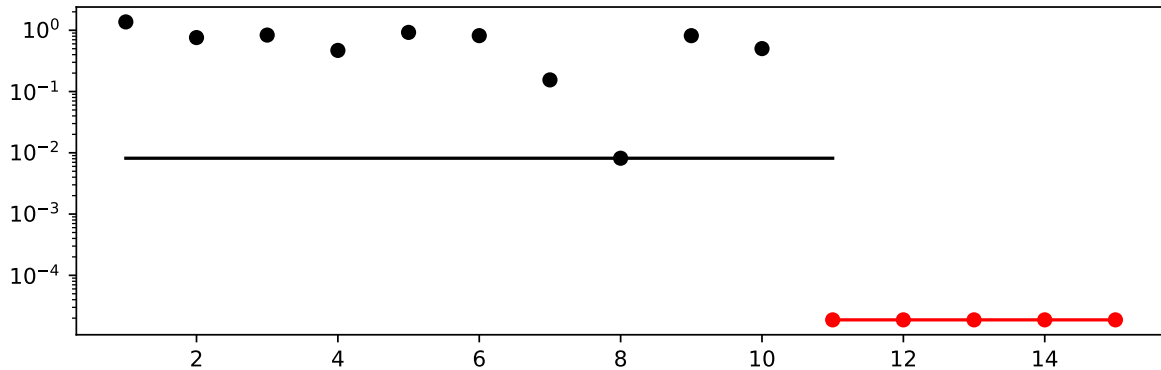
3.1.2 Results

```
spot_2.print_results()
```

```
min y: 1.8750731199649933e-05  
x0: 0.0015130475553084242  
x1: 0.0040572673433020325
```

```
[['x0', 0.0015130475553084242], ['x1', 0.0040572673433020325]]
```

```
spot_2.plot_progress(log_y=True)
```



3.2 Example With Anisotropic Kriging

- The default parameter setting of `spotPython`'s Kriging surrogate uses the same `theta` value for every dimension.
- This is referred to as “using an isotropic kernel”.
- If different `theta` values are used for each dimension, then an anisotropic kernel is used
- To enable anisotropic models in `spotPython`, the number of `theta` values should be larger than one.
- We can use `surrogate_control={"n_theta": 2}` to enable this behavior (2 is the problem dimension).

TensorBoard

Similar to the one-dimensional case, which was introduced in Section 1.7, we can use TensorBoard to monitor the progress of the optimization. We will use the same code, only the prefix is different:

```
from spotPython.utils.file import get_experiment_name
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_spot_tensorboard_path

PREFIX = "03"
experiment_name = get_experiment_name(prefix=PREFIX)
print(experiment_name)

fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name))
```

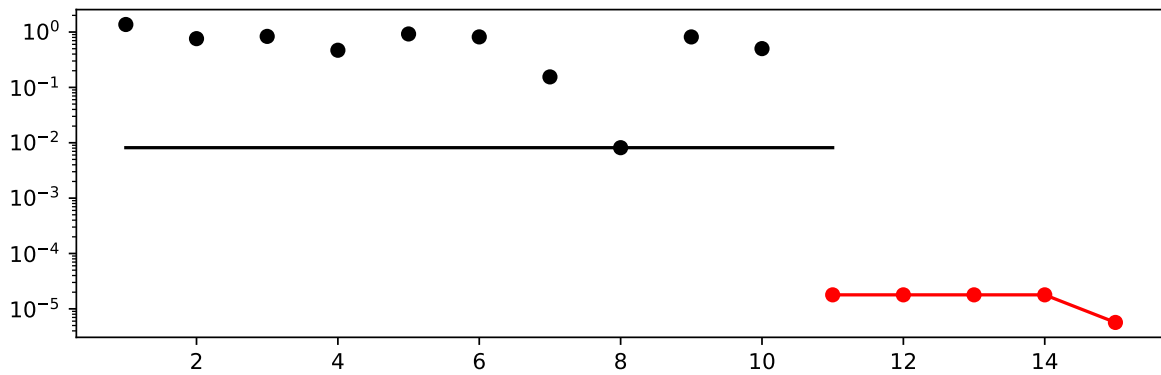
03_bartz08-2_2023-07-10_00-20-01

```
spot_2_anisotropic = spot.Spot(fun=fun,
                                lower = np.array([-1, -1]),
                                upper = np.array([1, 1]),
                                surrogate_control={"n_theta": 2},
                                fun_control=fun_control)
spot_2_anisotropic.run()
```

<spotPython.spot.spot.Spot at 0x2c30d3580>

- The search progress of the optimization with the anisotropic model can be visualized:

```
spot_2_anisotropic.plot_progress(log_y=True)
```



```
spot_2_anisotropic.print_results()
```

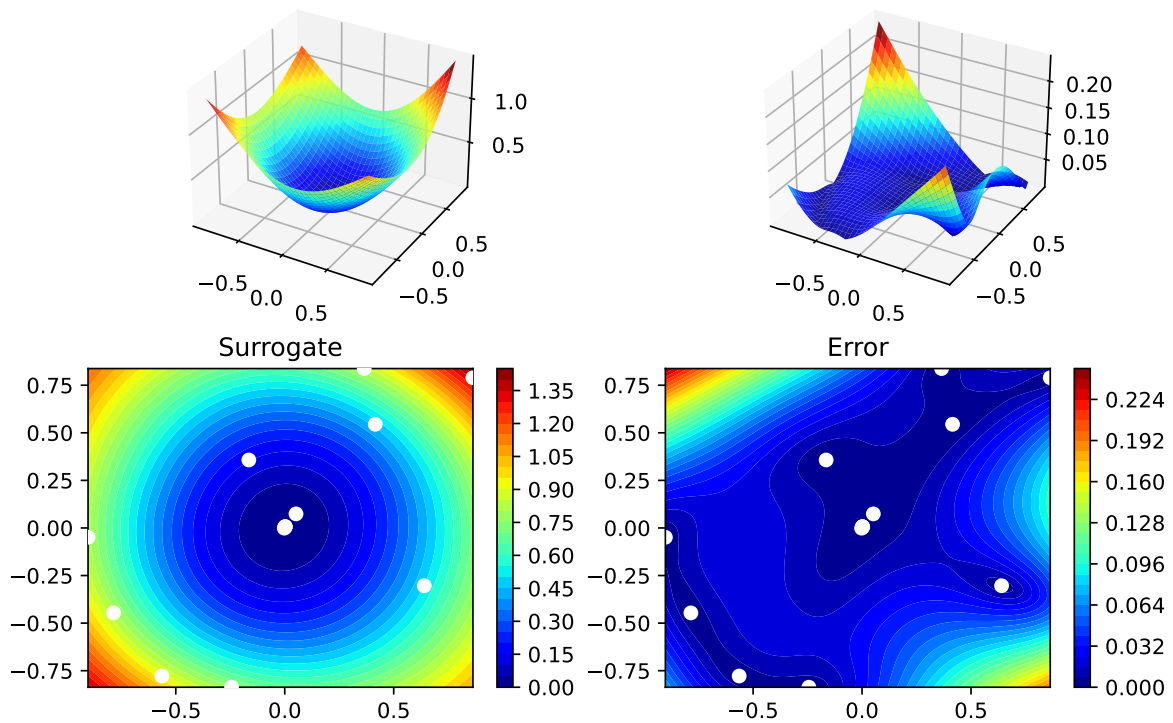
```
min y: 5.68261952864018e-06
```

```
x0: -0.002137037687426695
```

```
x1: -0.0010562620182313395
```

```
[['x0', -0.002137037687426695], ['x1', -0.0010562620182313395]]
```

```
spot_2_anisotropic.surrogate.plot()
```



3.2.1 Taking a Look at the `theta` Values

3.2.1.1 `theta` Values from the `spot` Model

- We can check, whether one or several `theta` values were used.
- The `theta` values from the surrogate can be printed as follows:

```
spot_2_anisotropic.surrogate.theta
```

```
array([0.16545225, 0.28999215])
```

- Since the surrogate from the isotropic setting was stored as `spot_2`, we can also take a look at the `theta` value from this model:

```
spot_2.surrogate.theta
```

```
array([0.26287446])
```

3.2.1.2 TensorBoard

Now we can start TensorBoard in the background with the following command:

```
tensorboard --logdir="./runs"
```

We can access the TensorBoard web server with the following URL:

```
http://localhost:6006/
```

The TensorBoard plot illustrates how **spotPython** can be used as a microscope for the internal mechanisms of the surrogate-based optimization process. Here, one important parameter, the learning rate θ of the Kriging surrogate is plotted against the number of optimization steps.

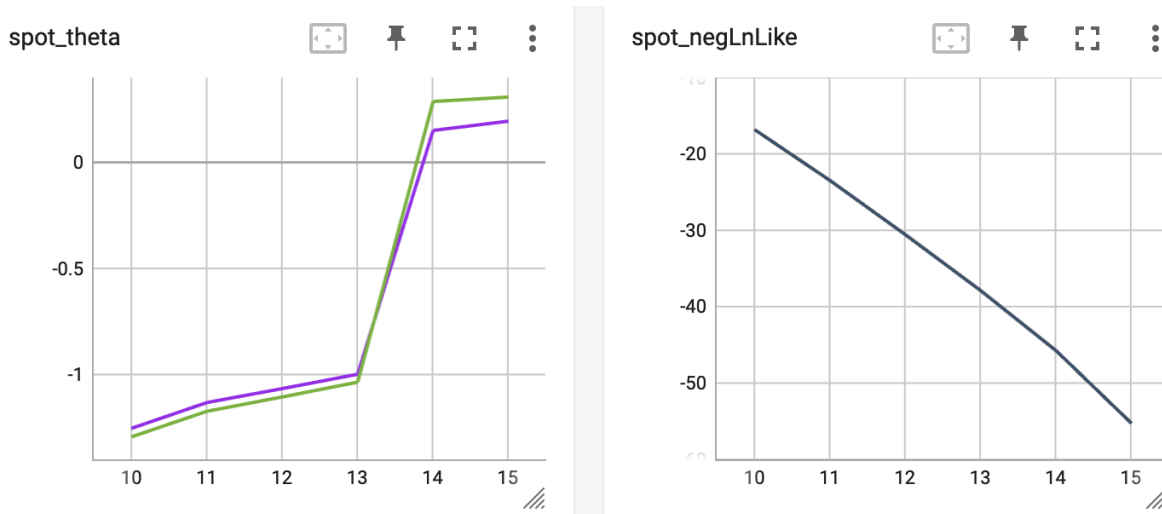


Figure 3.1: TensorBoard visualization of the **spotPython** surrogate model.

3.3 Exercises

3.3.1 fun_branin

- Describe the function.
 - The input dimension is 2. The search range is $-5 \leq x_1 \leq 10$ and $0 \leq x_2 \leq 15$.
- Compare the results from **spotPython** run a) with isotropic and b) anisotropic surrogate models.

- Modify the termination criterion: instead of the number of evaluations (which is specified via `fun_evals`), the time should be used as the termination criterion. This can be done as follows (`max_time=1` specifies a run time of one minute):

```
fun_evals=inf,
max_time=1,
```

3.3.2 fun_sin_cos

- Describe the function.
 - The input dimension is 2. The search range is $-2\pi \leq x_1 \leq 2\pi$ and $-2\pi \leq x_2 \leq 2\pi$.
- Compare the results from `spotPython` run a) with isotropic and b) anisotropic surrogate models.
- Modify the termination criterion (`max_time` instead of `fun_evals`) as described for `fun_branin`.

3.3.3 fun_runge

- Describe the function.
 - The input dimension is 2. The search range is $-5 \leq x_1 \leq 5$ and $-5 \leq x_2 \leq 5$.
- Compare the results from `spotPython` run a) with isotropic and b) anisotropic surrogate models.
- Modify the termination criterion (`max_time` instead of `fun_evals`) as described for `fun_branin`.

3.3.4 fun_wingwt

- Describe the function.
 - The input dimension is 10. The search ranges are between 0 and 1 (values are mapped internally to their natural bounds).
- Compare the results from `spotPython` run a) with isotropic and b) anisotropic surrogate models.
- Modify the termination criterion (`max_time` instead of `fun_evals`) as described for `fun_branin`.

4 Using sklearn Surrogates in spotPython

This notebook explains how different surrogate models from `scikit-learn` can be used as surrogates in `spotPython` optimization runs.

```
import numpy as np
from math import inf
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
```

4.1 Example: Branin Function with spotPython's Internal Kriging Surrogate

4.1.1 The Objective Function Branin

- The `spotPython` package provides several classes of objective functions.
- We will use an analytical objective function, i.e., a function that can be described by a (closed) formula.
- Here we will use the Branin function:

$y = a * (x_2 - b * x_1^2 + c * x_1 - r) ** 2 + s * (1 - t) * \cos(x_1) + s$,
where values of a , b , c , r , s and t are: $a = 1$, $b = 5.1 / (4 * \pi^2)$,
 $c = 5 / \pi$, $r = 6$, $s = 10$ and $t = 1 / (8 * \pi)$.

- It has three global minima:

$f(x) = 0.397887$ at $(-\pi, 12.275)$, $(\pi, 2.275)$, and $(9.42478, 2.475)$.

```
from spotPython.fun.objectivefunctions import analytical
lower = np.array([-5,-0])
upper = np.array([10,15])
```

```
fun = analytical().fun_branin
```


TensorBoard

Similar to the one-dimensional case, which was introduced in Section 1.7, we can use TensorBoard to monitor the progress of the optimization. We will use the same code, only the prefix is different:

```
from spotPython.utils.file import get_experiment_name
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_spot_tensorboard_path

PREFIX = "04"
experiment_name = get_experiment_name(prefix=PREFIX)
print(experiment_name)

fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name))
```

04_bartz08-2_2023-07-10_00-20-33

4.1.2 Running the surrogate model based optimizer Spot:

```
spot_2 = spot.Spot(fun=fun,
                  lower = lower,
                  upper = upper,
                  fun_evals = 20,
                  max_time = inf,
                  seed=123,
                  design_control={"init_size": 10},
                  fun_control=fun_control)

spot_2.run()
```

<spotPython.spot.spot.Spot at 0x1059782e0>

4.1.3 TensorBoard

Now we can start TensorBoard in the background with the following command:

```
tensorboard --logdir="./runs"
```

We can access the TensorBoard web server with the following URL:

```
http://localhost:6006/
```

The TensorBoard plot illustrates how `spotPython` can be used as a microscope for the internal mechanisms of the surrogate-based optimization process. Here, one important parameter, the learning rate θ of the Kriging surrogate is plotted against the number of optimization steps.

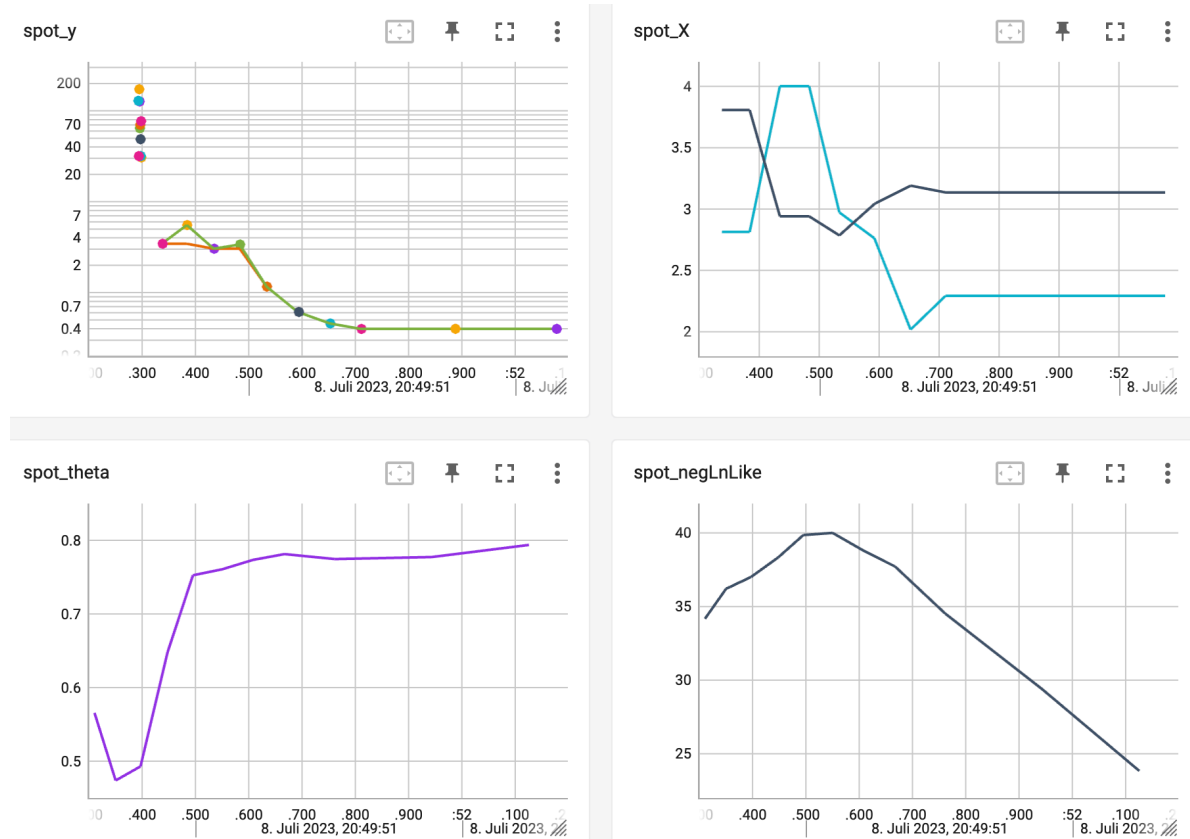


Figure 4.1: TensorBoard visualization of the `spotPython` optimization process and the surrogate model.

4.1.4 Print the Results

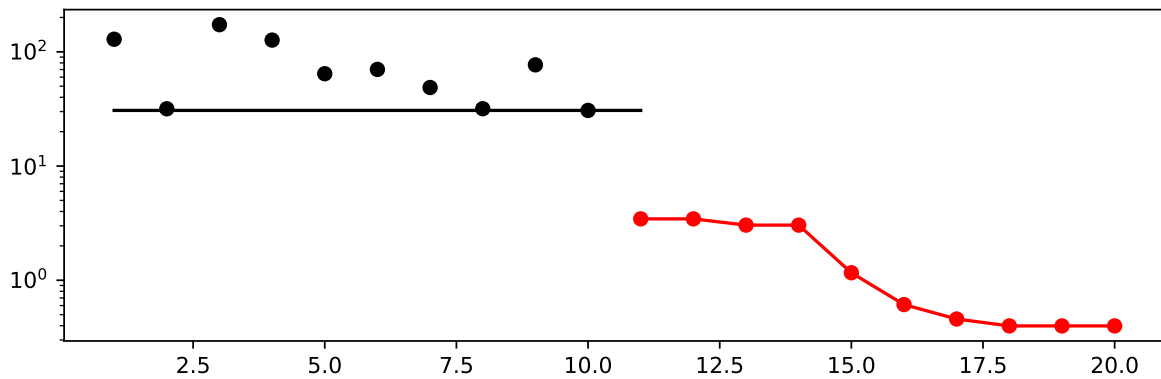
```
spot_2.print_results()
```

```
min y: 0.3983178342401956  
x0: 3.135416996435963  
x1: 2.2955490975636685
```

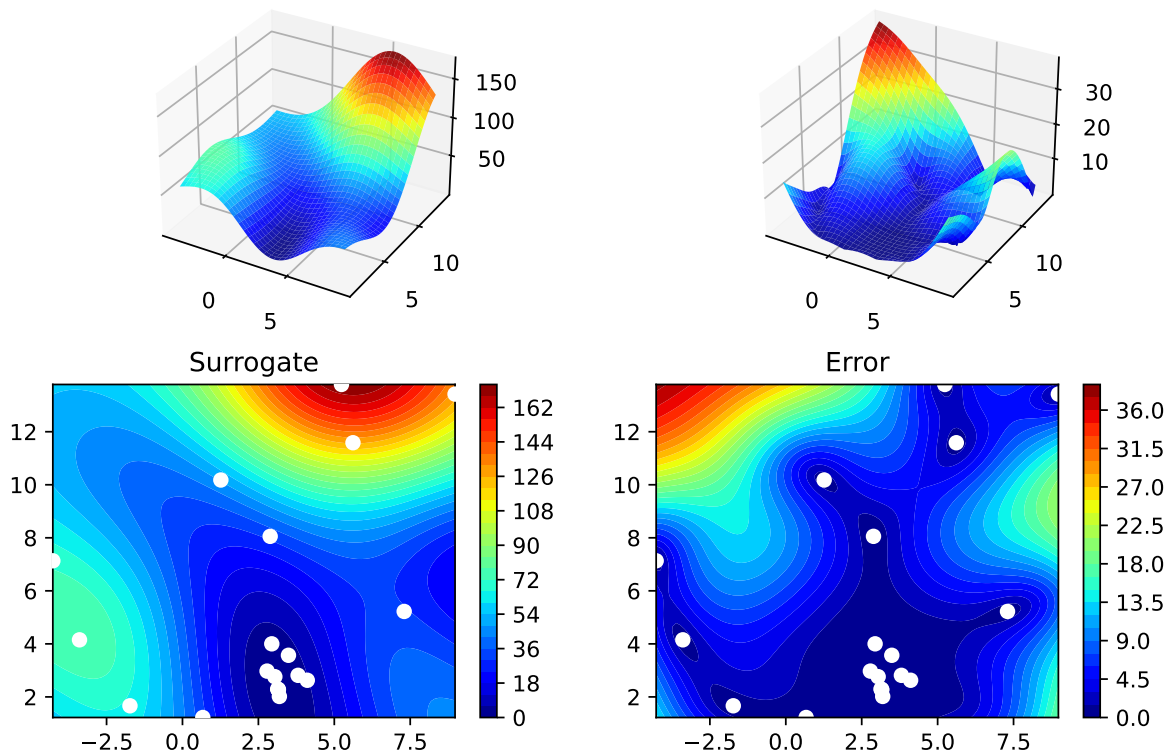
```
[['x0', 3.135416996435963], ['x1', 2.2955490975636685]]
```

4.1.5 Show the Progress and the Surrogate

```
spot_2.plot_progress(log_y=True)
```



```
spot_2.surrogate.plot()
```



4.2 Example: Using Surrogates From scikit-learn

- Default is the `spotPython` (i.e., the internal) kriging surrogate.
- It can be called explicitly and passed to `Spot`.

```
from spotPython.build.kriging import Kriging
S_0 = Kriging(name='kriging', seed=123)
```

- Alternatively, models from `scikit-learn` can be selected, e.g., Gaussian Process, RBFs, Regression Trees, etc.

```
# Needed for the sklearn surrogates:
from sklearn.gaussian_process import GaussianProcessRegressor
from sklearn.gaussian_process.kernels import RBF
from sklearn.tree import DecisionTreeRegressor
from sklearn.ensemble import RandomForestRegressor
from sklearn import linear_model
```

```
from sklearn import tree
import pandas as pd
```

- Here are some additional models that might be useful later:

```
S_Tree = DecisionTreeRegressor(random_state=0)
S_LM = linear_model.LinearRegression()
S_Ridge = linear_model.Ridge()
S_RF = RandomForestRegressor(max_depth=2, random_state=0)
```

4.2.1 GaussianProcessRegressor as a Surrogate

- To use a Gaussian Process model from `sklearn`, that is similar to `spotPython`'s Kriging, we can proceed as follows:

```
kernel = 1 * RBF(length_scale=1.0, length_scale_bounds=(1e-2, 1e2))
S_GP = GaussianProcessRegressor(kernel=kernel, n_restarts_optimizer=9)
```

- The scikit-learn GP model `S_GP` is selected for `Spot` as follows:

```
surrogate = S_GP
```

- We can check the kind of surrogate model with the command `isinstance`:

```
isinstance(S_GP, GaussianProcessRegressor)
```

True

```
isinstance(S_0, Kriging)
```

True

- Similar to the `Spot` run with the internal `Kriging` model, we can call the run with the `scikit-learn` surrogate:

```
fun = analytical(seed=123).fun_branin
spot_2_GP = spot.Spot(fun=fun,
                      lower = lower,
                      upper = upper,
```

```

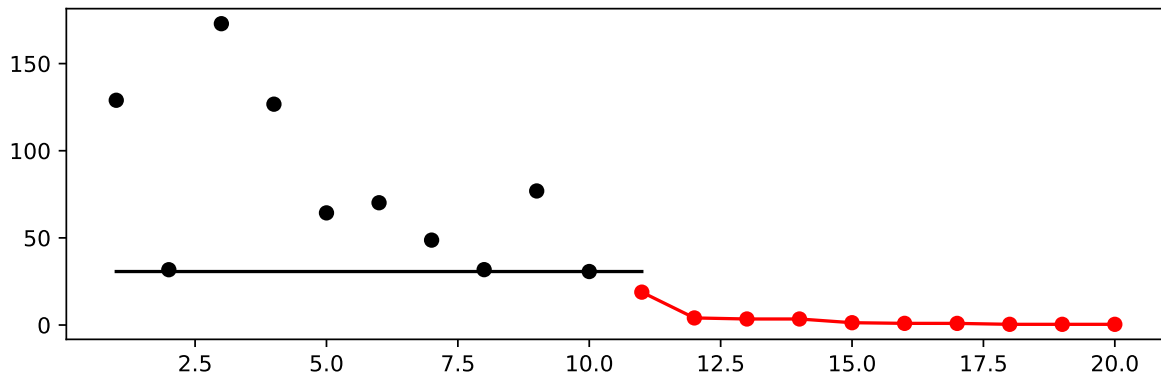
        fun_evals = 20,
        seed=123,
        design_control={"init_size": 10},
        surrogate = S_GP)

spot_2_GP.run()

```

<spotPython.spot.spot.Spot at 0x2bd6353f0>

```
spot_2_GP.plot_progress()
```



```
spot_2_GP.print_results()
```

```

min y: 0.3981631812933486
x0: 3.1491652274330053
x1: 2.2698186003445153

```

```
[['x0', 3.1491652274330053], ['x1', 2.2698186003445153]]
```

4.3 Example: One-dimensional Sphere Function With spotPython's Kriging

- In this example, we will use an one-dimensional function, which allows us to visualize the optimization process.
 - `show_models= True` is added to the argument list.

```

from spotPython.fun.objectivefunctions import analytical
lower = np.array([-1])
upper = np.array([1])
fun = analytical(seed=123).fun_sphere

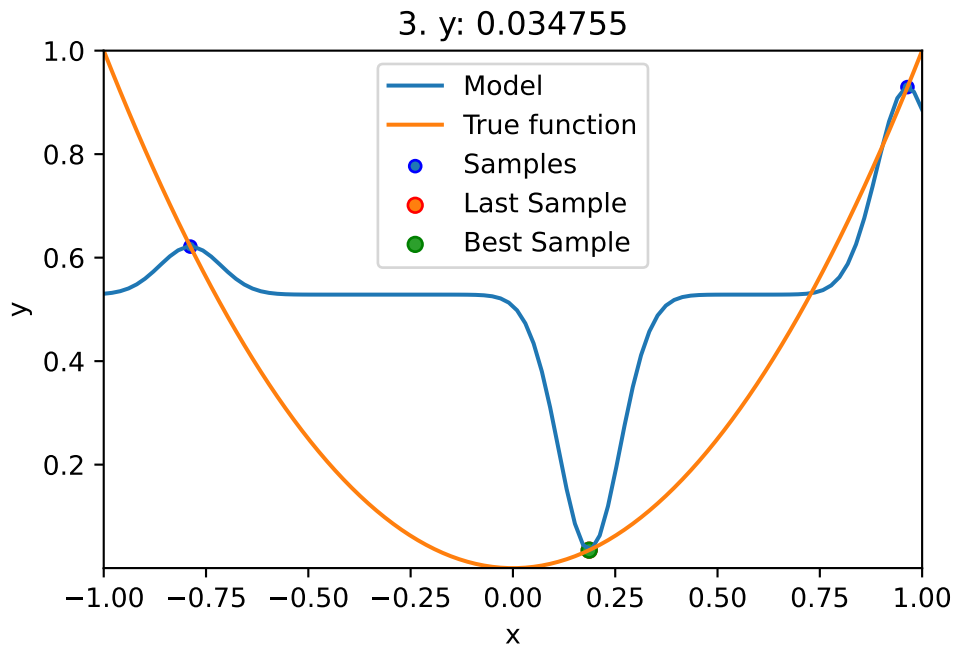
```

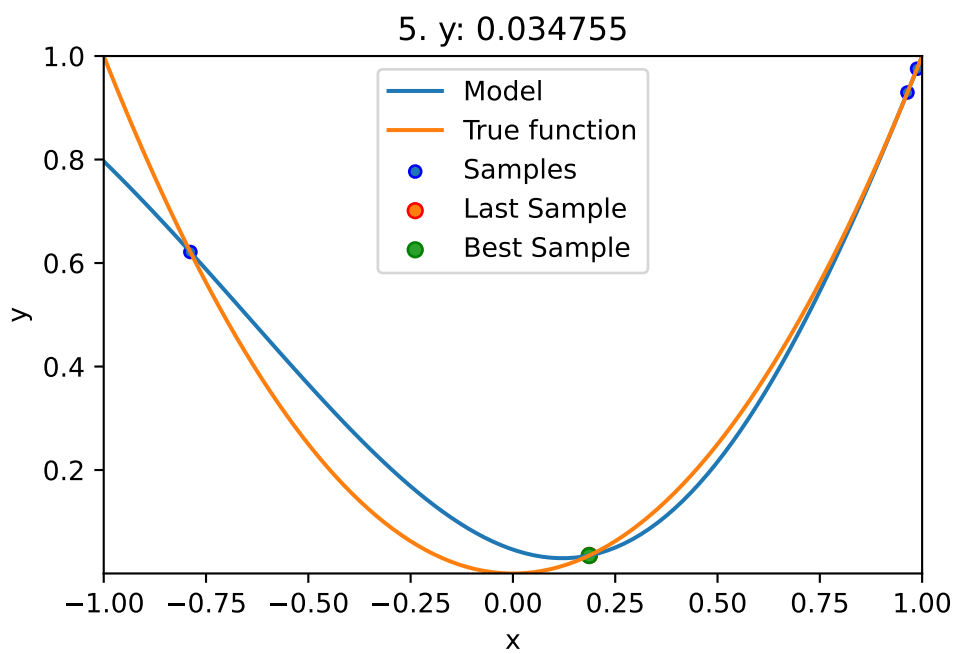
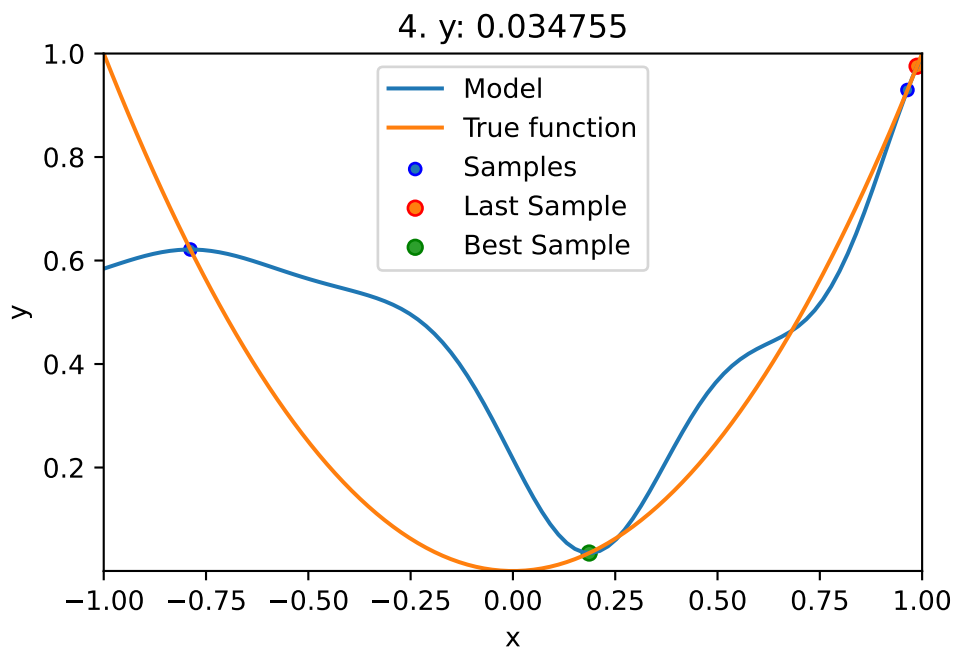
```

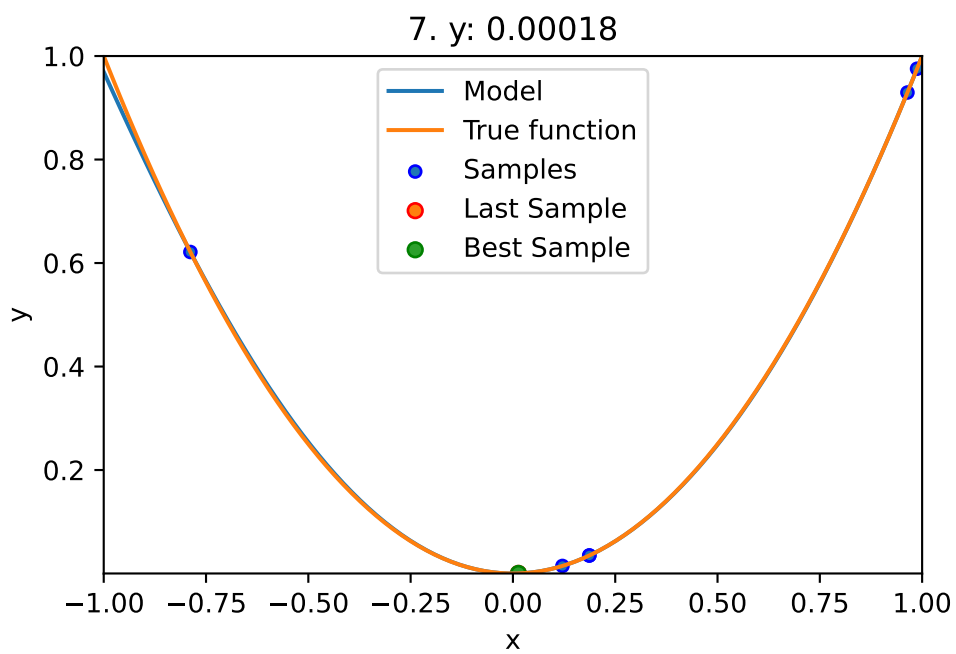
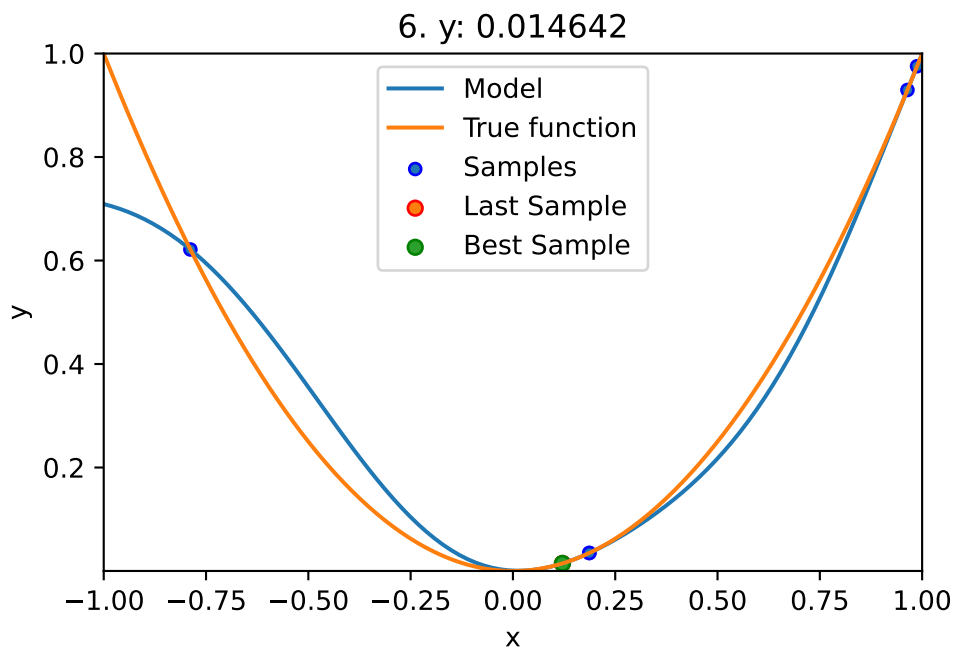
spot_1 = spot.Spot(fun=fun,
                    lower = lower,
                    upper = upper,
                    fun_evals = 10,
                    max_time = inf,
                    seed=123,
                    show_models= True,
                    tolerance_x = np.sqrt(np.spacing(1)),
                    design_control={"init_size": 3},)

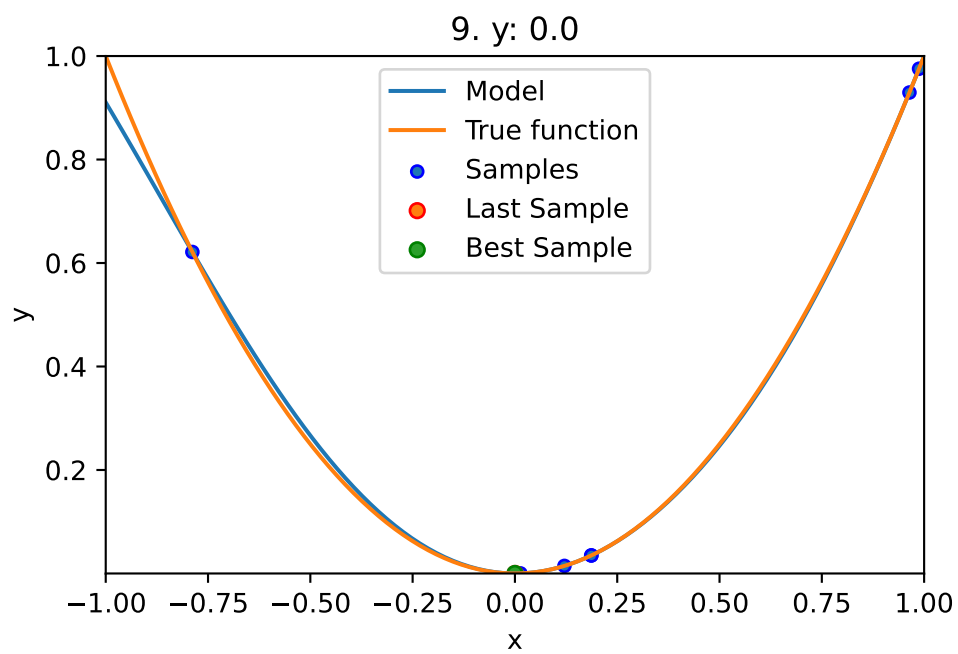
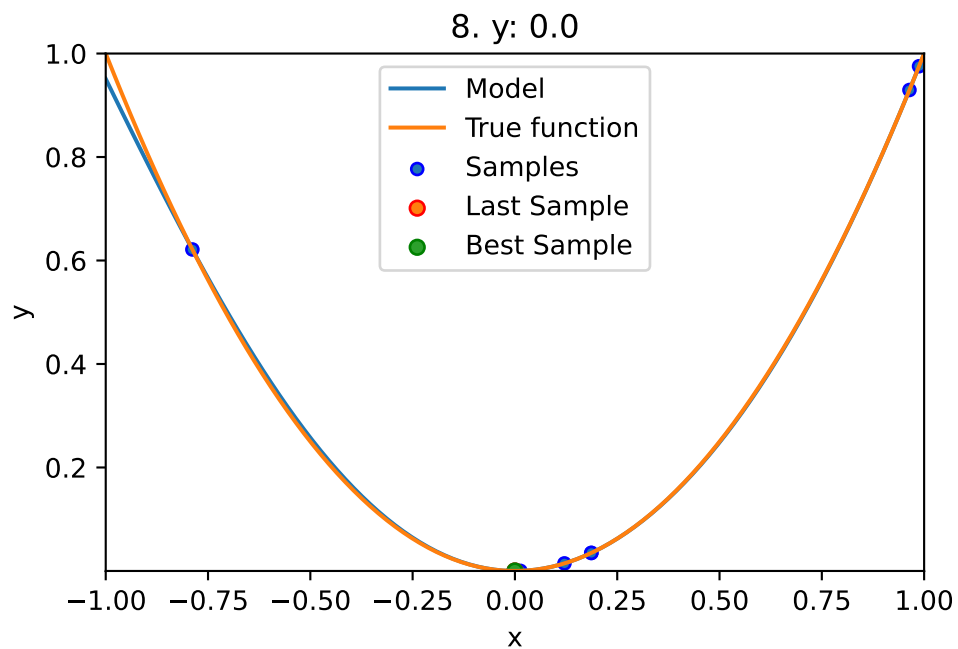
spot_1.run()

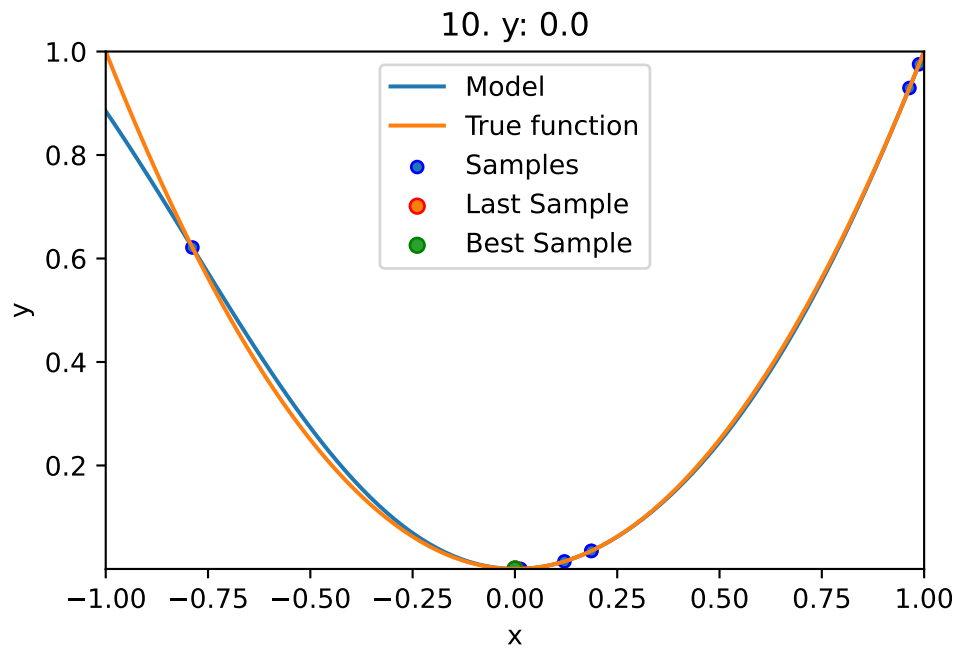
```











<spotPython.spot.spot.Spot at 0x2c0e05f90>

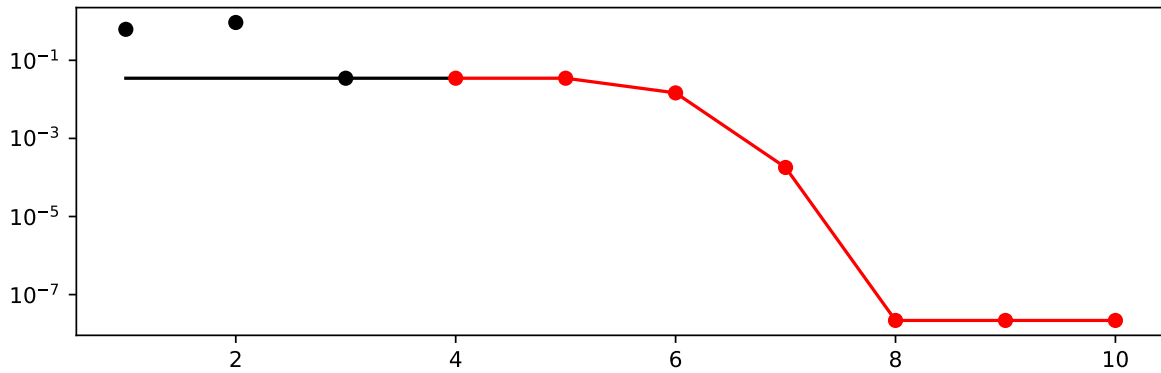
4.3.1 Results

```
spot_1.print_results()
```

```
min y: 2.1786524623022742e-08  
x0: -0.00014760259016366462
```

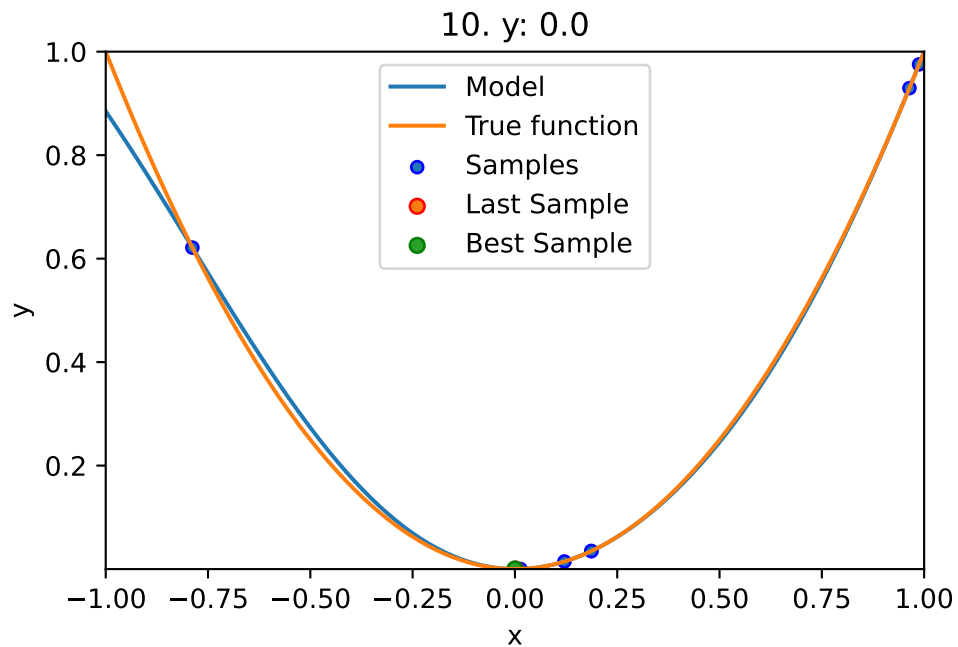
```
[['x0', -0.00014760259016366462]]
```

```
spot_1.plot_progress(log_y=True)
```



- The method `plot_model` plots the final surrogate:

```
spot_1.plot_model()
```



4.4 Example: Sklearn Model GaussianProcess

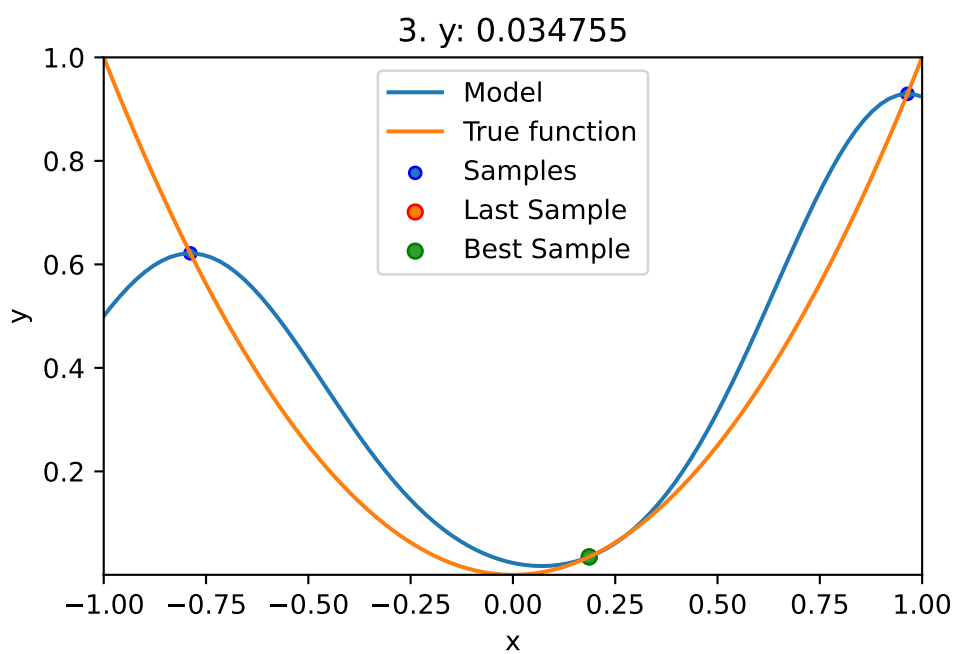
- This example visualizes the search process on the `GaussianProcessRegression` surrogate from `sklearn`.
- Therefore `surrogate = S_GP` is added to the argument list.

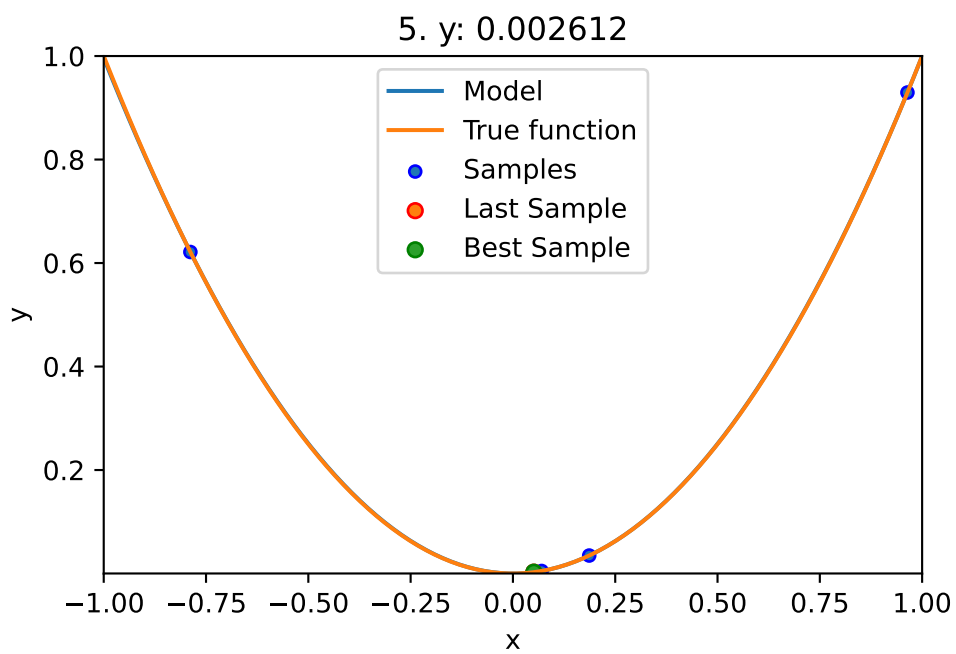
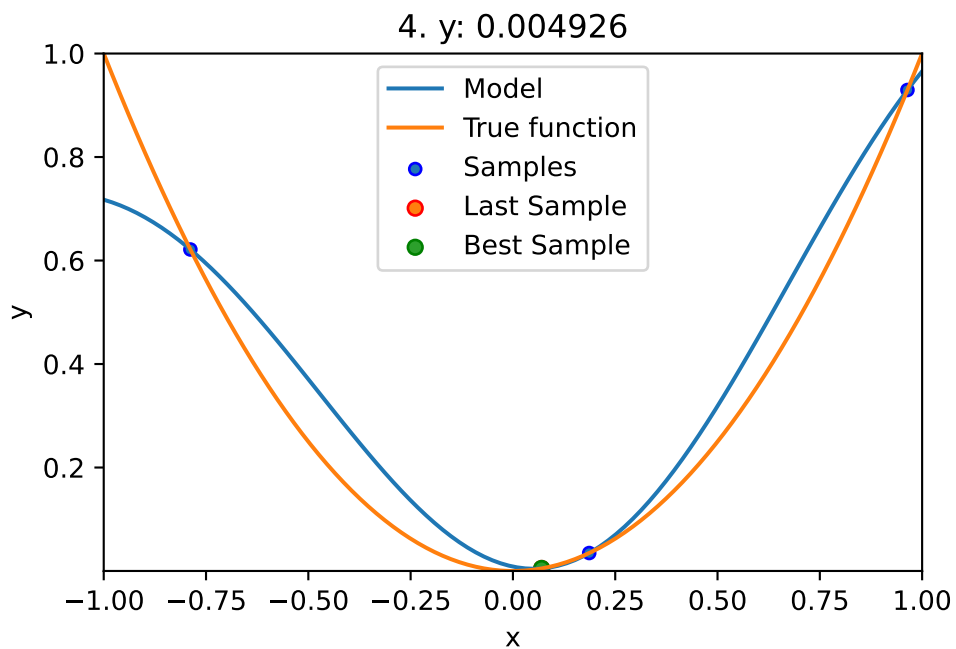
```

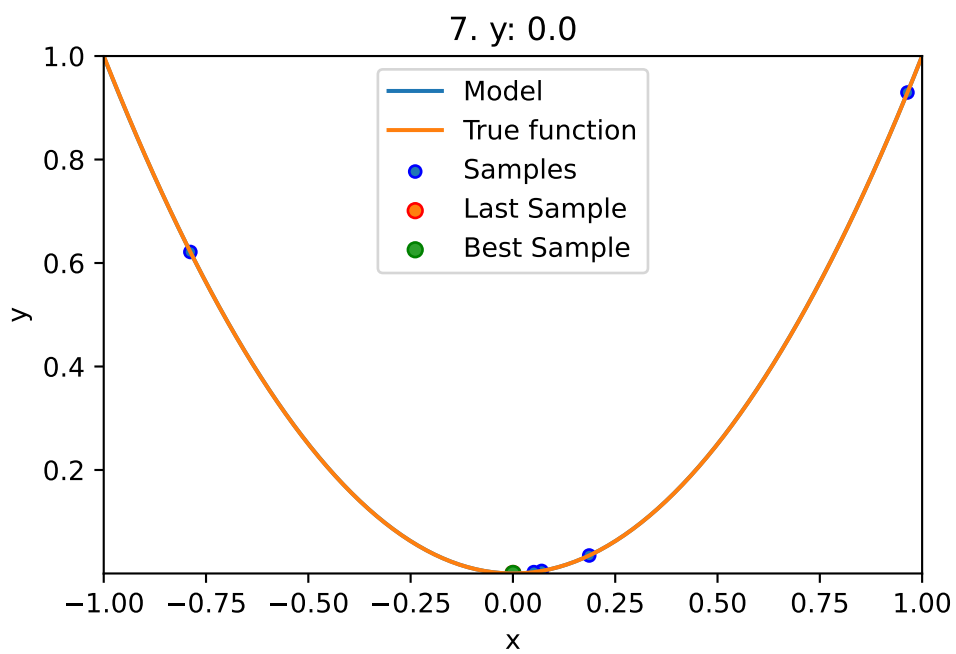
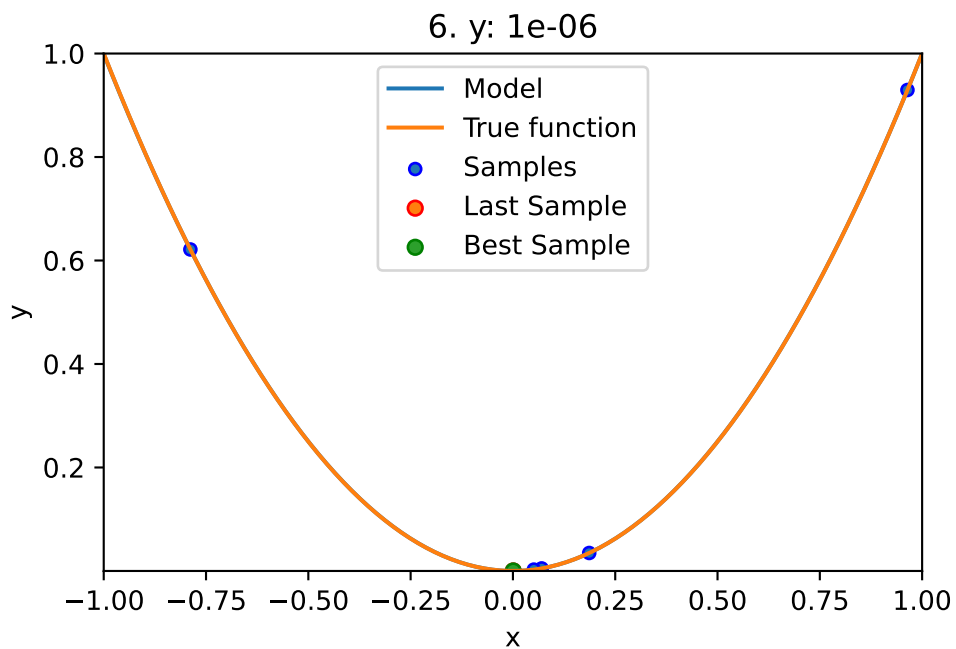
fun = analytical(seed=123).fun_sphere
spot_1_GP = spot.Spot(fun=fun,
                      lower = lower,
                      upper = upper,
                      fun_evals = 10,
                      max_time = inf,
                      seed=123,
                      show_models= True,
                      design_control={"init_size": 3},
                      surrogate = S_GP)

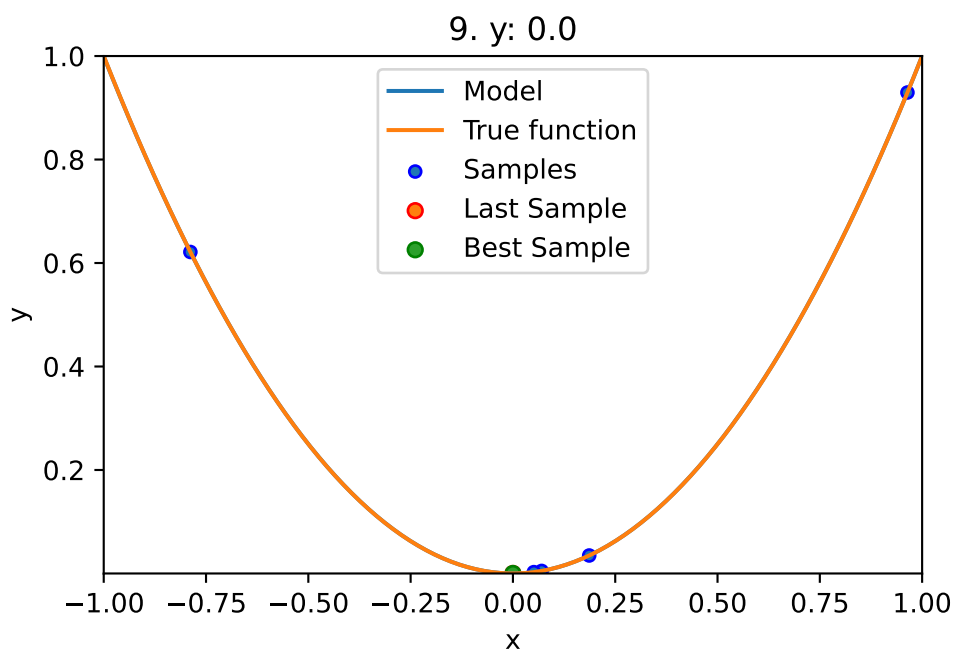
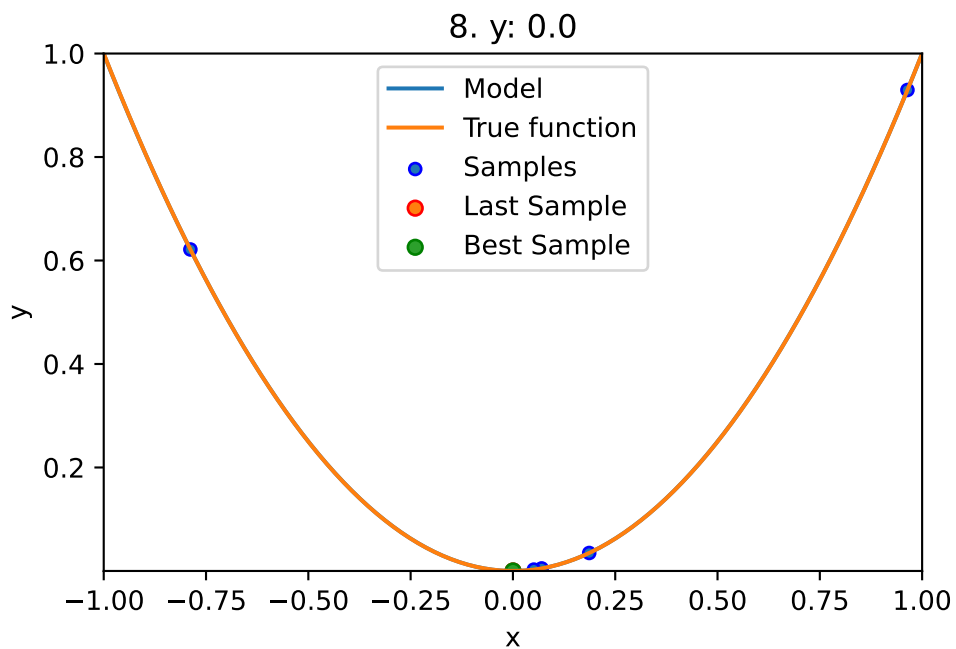
spot_1_GP.run()

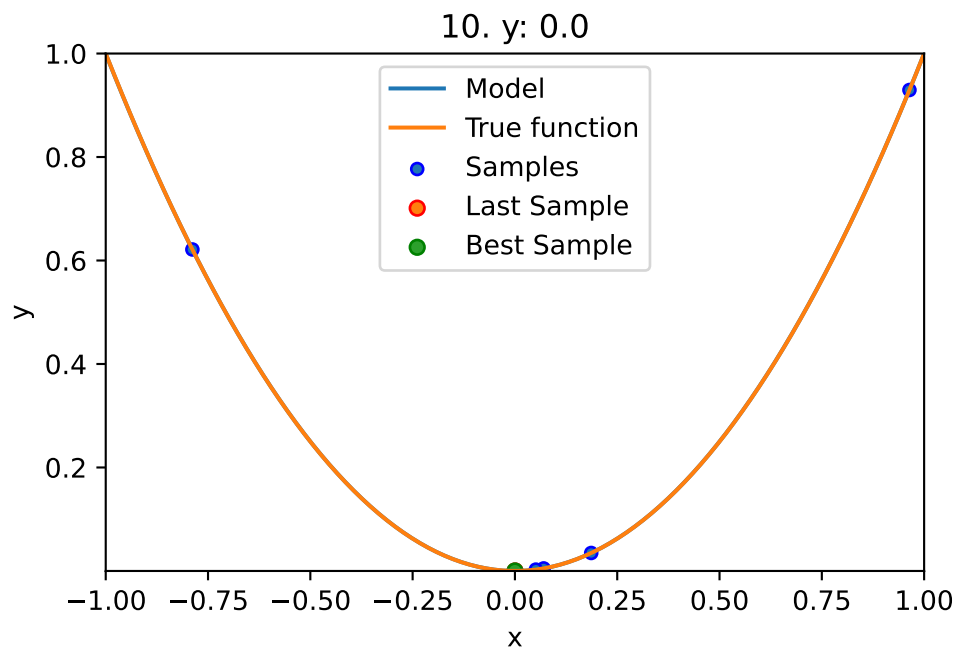
```











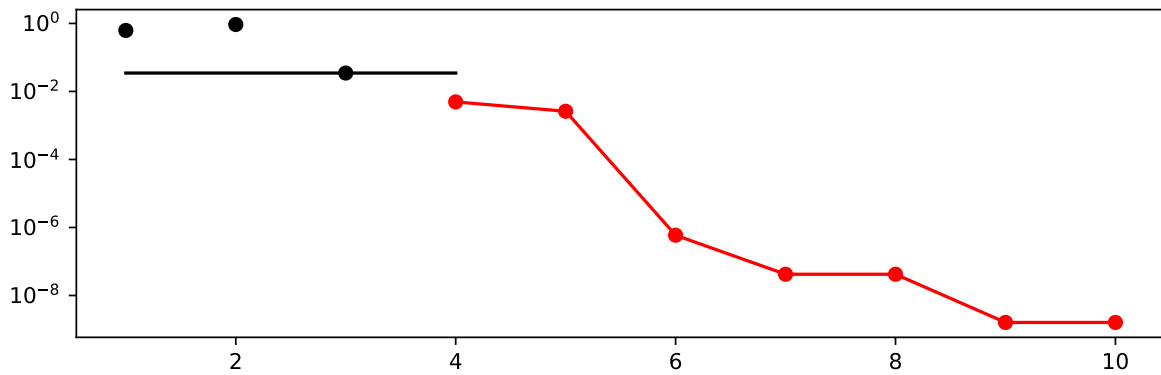
```
<spotPython.spot.spot.Spot at 0x2c25db6a0>
```

```
spot_1_GP.print_results()
```

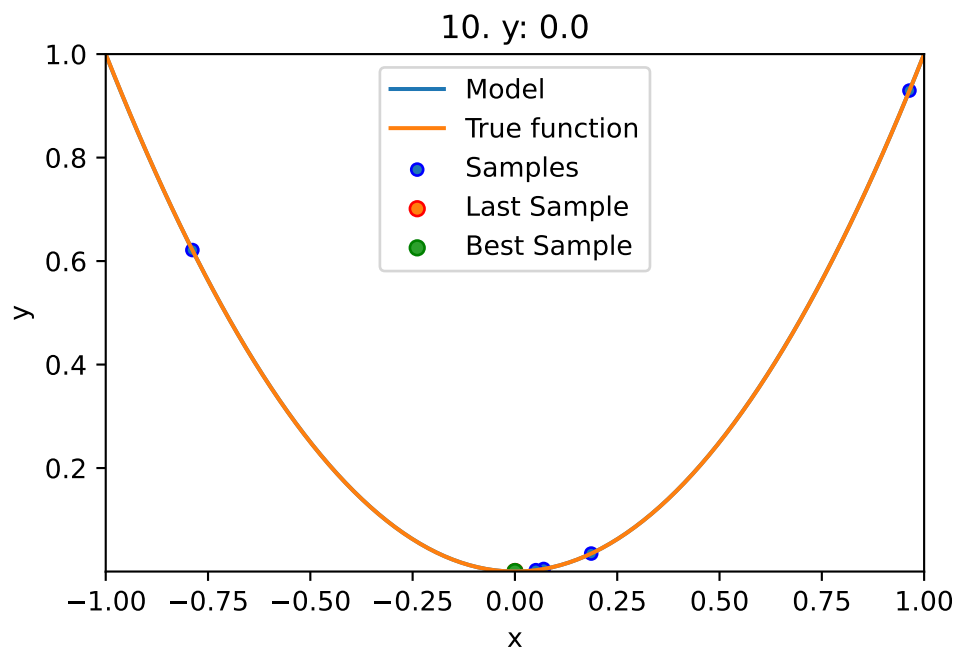
```
min y: 1.6119389142446866e-09  
x0: 4.0148959068009304e-05
```

```
[['x0', 4.0148959068009304e-05]]
```

```
spot_1_GP.plot_progress(log_y=True)
```



```
spot_1_GP.plot_model()
```



4.5 Exercises

4.5.1 DecisionTreeRegressor

- Describe the surrogate model.
- Use the surrogate as the model for optimization.

4.5.2 RandomForestRegressor

- Describe the surrogate model.
- Use the surrogate as the model for optimization.

4.5.3 linear_model.LinearRegression

- Describe the surrogate model.
- Use the surrogate as the model for optimization.

4.5.4 linear_model.Ridge

- Describe the surrogate model.
- Use the surrogate as the model for optimization.

4.6 Exercise 2

- Compare the performance of the five different surrogates on both objective functions:
 - spotPython's internal Kriging
 - DecisionTreeRegressor
 - RandomForestRegressor
 - linear_model.LinearRegression
 - linear_model.Ridge

5 Sequential Parameter Optimization: Using scipy Optimizers

This notebook describes how different optimizers from the `scipy optimize` package can be used on the surrogate. The optimization algorithms are available from <https://docs.scipy.org/doc/scipy/reference/optimize.html>

```
import numpy as np
from math import inf
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
from scipy.optimize import shgo
from scipy.optimize import direct
from scipy.optimize import differential_evolution
from scipy.optimize import dual_annealing
from scipy.optimize import basinhopping
```

5.1 The Objective Function Branin

- The `spotPython` package provides several classes of objective functions.
- We will use an analytical objective function, i.e., a function that can be described by a (closed) formula.
- Here we will use the Branin function. The 2-dim Branin function is

$$y = a * (x_2 - b * x_1^2 + c * x_1 - r)^2 + s * (1 - t) * \cos(x_1) + s,$$

where values of a , b , c , r , s and t are: $a = 1$, $b = 5.1/(4 * \pi^2)$, $c = 5/\pi$, $r = 6$, $s = 10$ and $t = 1/(8 * \pi)$.

- It has three global minima:
 $f(x) = 0.397887$ at $(-\pi, 12.275)$, $(\pi, 2.275)$, and $(9.42478, 2.475)$.
- Input Domain: This function is usually evaluated on the square x_1 in $[-5, 10]$ x x_2 in $[0, 15]$.

```

from spotPython.fun.objectivefunctions import analytical
lower = np.array([-5,-0])
upper = np.array([10,15])

fun = analytical(seed=123).fun_branin

```

5.2 The Optimizer

- Differential Evolution from the `scikit.optimize` package, see https://docs.scipy.org/doc/scipy/reference/generated/scipy.optimize.differential_evolution.html#scipy.optimize.differential_evolution is the default optimizer for the search on the surrogate.
- Other optimizers that are available in `spotPython`:

- `dual_annealing`
- `direct`
- `shgo`
- `basinhopping`, see <https://docs.scipy.org/doc/scipy/reference/optimize.html#global-optimization>.

- These can be selected as follows:

```
surrogate_control = "model_optimizer": differential_evolution
```

- We will use `differential_evolution`.
- The optimizer can use 1000 evaluations. This value will be passed to the `differential_evolution` method, which has the argument `maxiter` (int). It defines the maximum number of generations over which the entire differential evolution population is evolved, see https://docs.scipy.org/doc/scipy/reference/generated/scipy.optimize.differential_evolution.html#scipy.optimize.differential_evolution

i TensorBoard

Similar to the one-dimensional case, which was introduced in Section 1.7, we can use TensorBoard to monitor the progress of the optimization. We will use the same code, only the prefix is different:

```

from spotPython.utils.file import get_experiment_name
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_spot_tensorboard_path

PREFIX = "05_DE_"
experiment_name = get_experiment_name(prefix=PREFIX)
print(experiment_name)

fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name))

```

05_DE__bartz08-2_2023-07-10_00-21-06

```

spot_de = spot.Spot(fun=fun,
                    lower = lower,
                    upper = upper,
                    fun_evals = 20,
                    max_time = inf,
                    seed=125,
                    noise=False,
                    show_models= False,
                    design_control={"init_size": 10},
                    surrogate_control={"n_theta": len(lower),
                                     "model_optimizer": differential_evolution,
                                     "model_fun_evals": 1000,
                                     },
                    fun_control=fun_control)

spot_de.run()

```

<spotPython.spot.spot.Spot at 0x107918ca0>

5.2.1 TensorBoard

Now we can start TensorBoard in the background with the following command:

```
tensorboard --logdir="./runs"
```

We can access the TensorBoard web server with the following URL:

<http://localhost:6006/>

The TensorBoard plot illustrates how `spotPython` can be used as a microscope for the internal mechanisms of the surrogate-based optimization process. Here, one important parameter, the learning rate θ of the Kriging surrogate is plotted against the number of optimization steps.

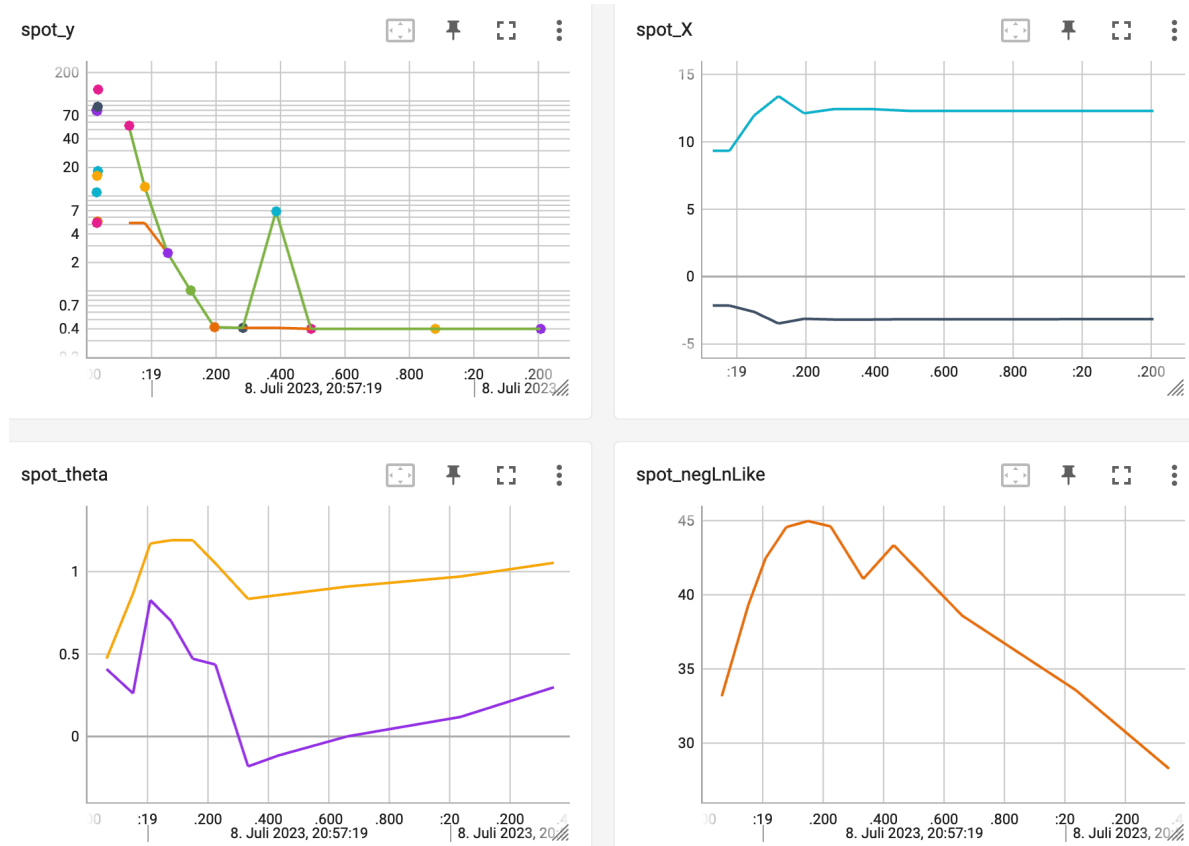


Figure 5.1: TensorBoard visualization of the `spotPython` optimization process and the surrogate model.

5.3 Print the Results

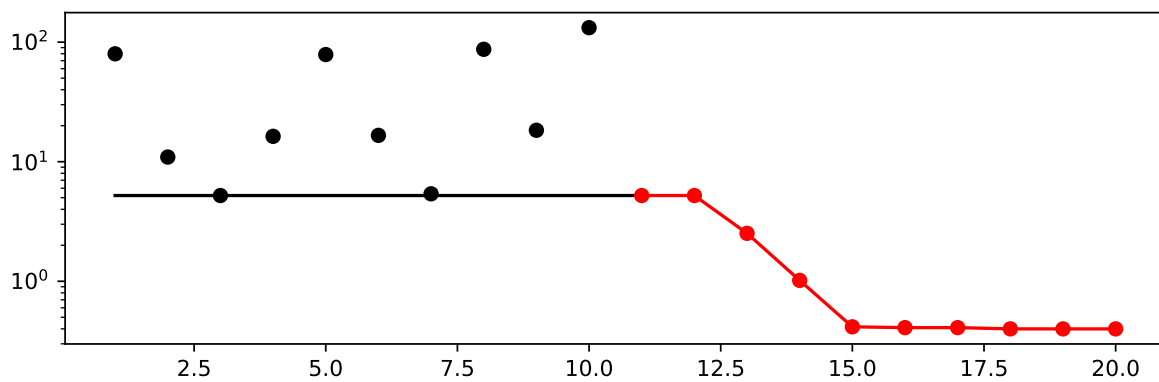
```
spot_de.print_results()
```

```
min y: 0.39969164980122684
x0: -3.158224446089584
x1: 12.293182279400076
```

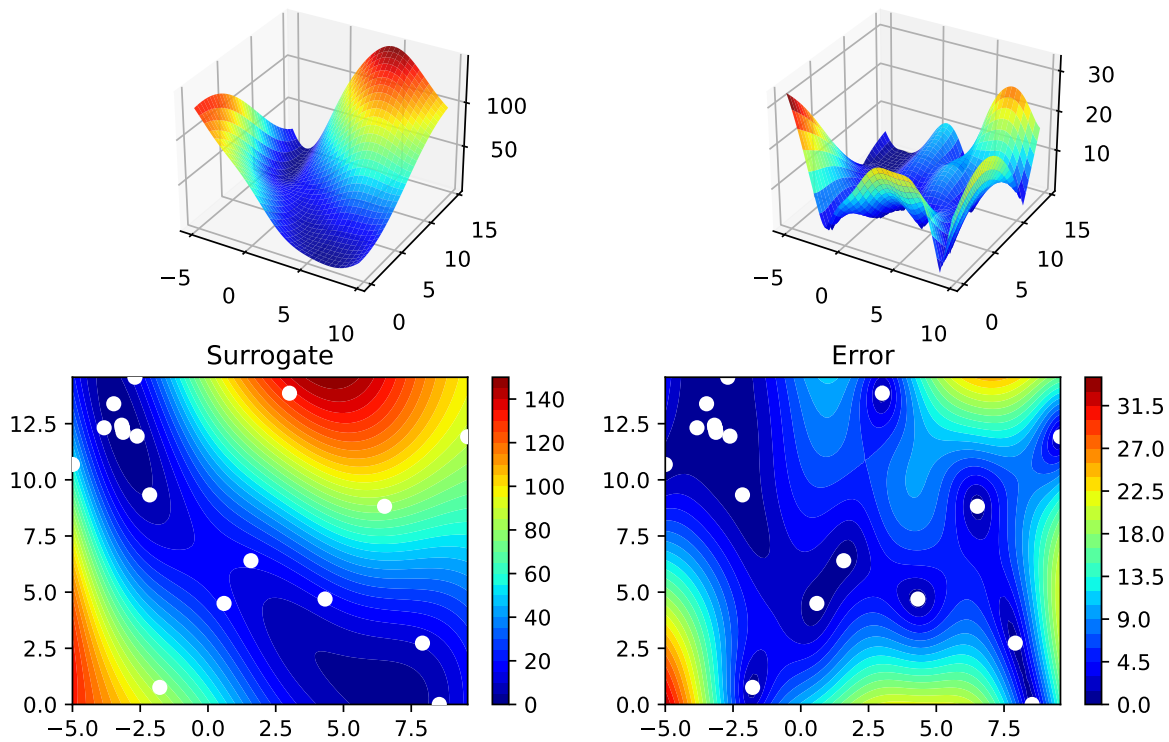
```
[['x0', -3.158224446089584], ['x1', 12.293182279400076]]
```

5.4 Show the Progress

```
spot_de.plot_progress(log_y=True)
```



```
spot_de.surrogate.plot()
```

5.5 Exercises

5.5.1 `dual_annealing`

- Describe the optimization algorithm
- Use the algorithm as an optimizer on the surrogate

5.5.2 `direct`

- Describe the optimization algorithm
- Use the algorithm as an optimizer on the surrogate

5.5.3 `shgo`

- Describe the optimization algorithm
- Use the algorithm as an optimizer on the surrogate

5.5.4 basinhopping

- Describe the optimization algorithm
- Use the algorithm as an optimizer on the surrogate

5.5.5 Performance Comparison

Compare the performance and run time of the 5 different optimizers:

```
* `differential_evolution`  
* `dual_annealing`  
* `direct`  
* `shgo`  
* `basinhopping`.
```

The Branin function has three global minima:

- $f(x) = 0.397887$ at
 - $(-\pi, 12.275)$,
 - $(\pi, 2.275)$, and
 - $(9.42478, 2.475)$.
- Which optima are found by the optimizers? Does the **seed** change this behavior?

6 Sequential Parameter Optimization: Gaussian Process Models

- This notebook analyzes differences between
 - the Kriging implementation in `spotPython` and
 - the `GaussianProcessRegressor` in `scikit-learn`.

```
import numpy as np
from math import inf
from spotPython.fun.objectivefunctions import analytical
from spotPython.design.spacefilling import spacefilling
from spotPython.spot import spot
from spotPython.build.kriging import Kriging
from scipy.optimize import shgo
from scipy.optimize import direct
from scipy.optimize import differential_evolution
import matplotlib.pyplot as plt
import math as m
from sklearn.gaussian_process import GaussianProcessRegressor
from sklearn.gaussian_process.kernels import RBF
```

6.1 Gaussian Processes Regression: Basic Introductory `scikit-learn` Example

- This is the example from `scikit-learn`: https://scikit-learn.org/stable/auto_examples/gaussian_process/plot_gpr.html
- After fitting our model, we see that the hyperparameters of the kernel have been optimized.
- Now, we will use our kernel to compute the mean prediction of the full dataset and plot the 95% confidence interval.

6.1.1 Train and Test Data

```
X = np.linspace(start=0, stop=10, num=1_000).reshape(-1, 1)
y = np.squeeze(X * np.sin(X))
rng = np.random.RandomState(1)
training_indices = rng.choice(np.arange(y.size), size=6, replace=False)
X_train, y_train = X[training_indices], y[training_indices]
```

6.1.2 Building the Surrogate With Sklearn

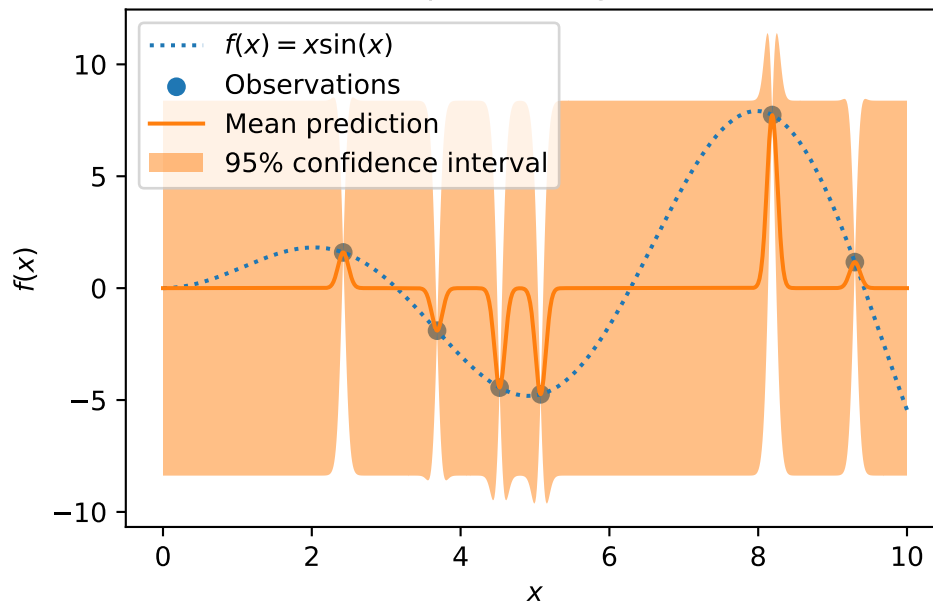
- The model building with `sklearn` consists of three steps:
 1. Instantiating the model, then
 2. fitting the model (using `fit`), and
 3. making predictions (using `predict`)

```
kernel = 1 * RBF(length_scale=1.0, length_scale_bounds=(1e-2, 1e2))
gaussian_process = GaussianProcessRegressor(kernel=kernel, n_restarts_optimizer=9)
gaussian_process.fit(X_train, y_train)
mean_prediction, std_prediction = gaussian_process.predict(X, return_std=True)
```

6.1.3 Plotting the SklearnModel

```
plt.plot(X, y, label=r"$f(x) = x \sin(x)$", linestyle="dotted")
plt.scatter(X_train, y_train, label="Observations")
plt.plot(X, mean_prediction, label="Mean prediction")
plt.fill_between(
    X.ravel(),
    mean_prediction - 1.96 * std_prediction,
    mean_prediction + 1.96 * std_prediction,
    alpha=0.5,
    label=r"95% confidence interval",
)
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("sk-learn Version: Gaussian process regression on noise-free dataset")
```

sk-learn Version: Gaussian process regression on noise-free dataset



6.1.4 The spotPython Version

- The spotPython version is very similar:
 1. Instantiating the model, then
 2. fitting the model and
 3. making predictions (using `predict`).

```
S = Kriging(name='kriging', seed=123, log_level=50, cod_type="norm")
S.fit(X_train, y_train)
S_mean_prediction, S_std_prediction, S_ei = S.predict(X, return_val="all")
```

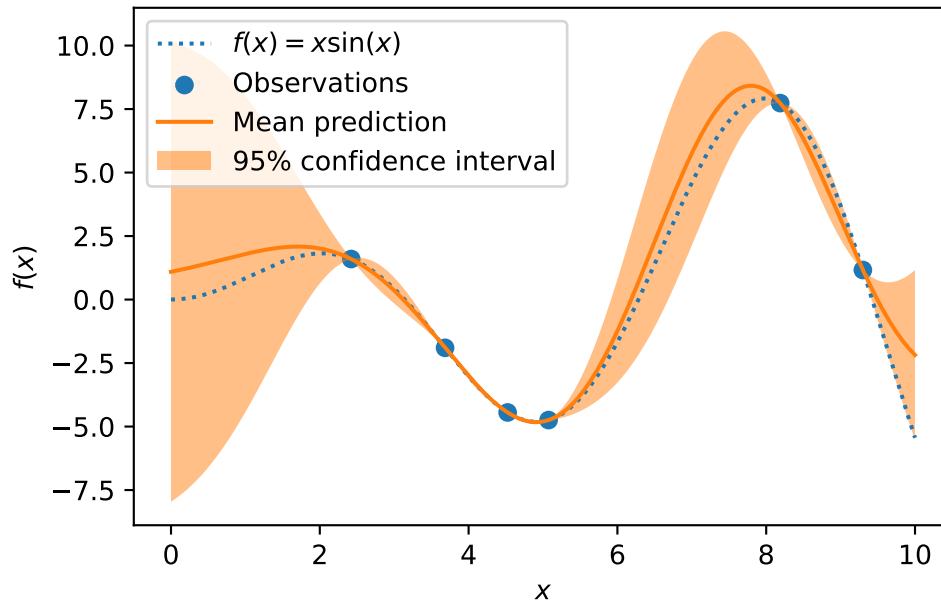
```
plt.plot(X, y, label=r"$f(x) = x \sin(x)$", linestyle="dotted")
plt.scatter(X_train, y_train, label="Observations")
plt.plot(X, S_mean_prediction, label="Mean prediction")
plt.fill_between(
    X.ravel(),
    S_mean_prediction - 1.96 * S_std_prediction,
    S_mean_prediction + 1.96 * S_std_prediction,
    alpha=0.5,
    label=r"95% confidence interval",
```

```

)
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("spotPython Version: Gaussian process regression on noise-free dataset")

```

spotPython Version: Gaussian process regression on noise-free dataset

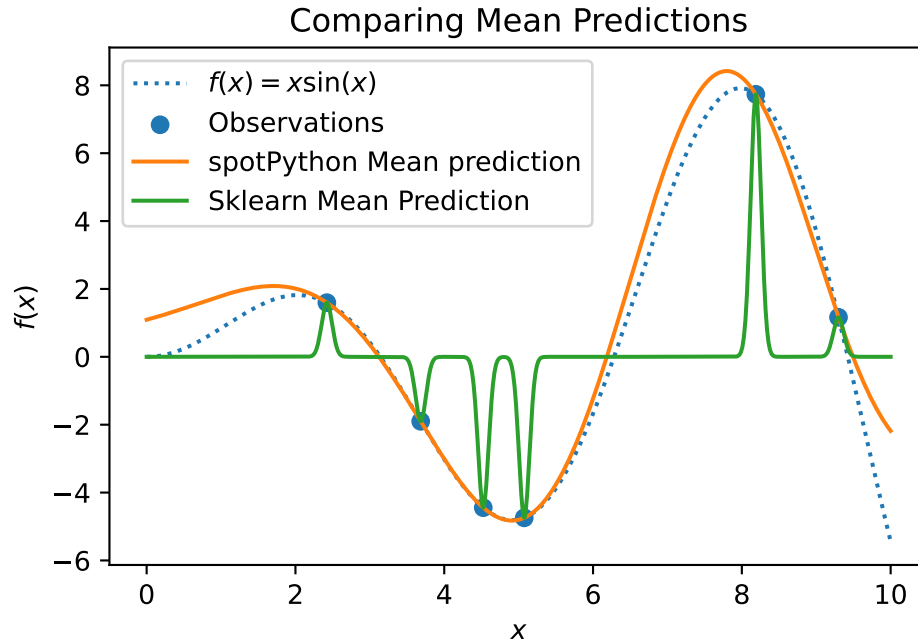


6.1.5 Visualizing the Differences Between the spotPython and the sklearn Model Fits

```

plt.plot(X, y, label=r"$f(x) = x \sin(x)$", linestyle="dotted")
plt.scatter(X_train, y_train, label="Observations")
plt.plot(X, S_mean_prediction, label="spotPython Mean prediction")
plt.plot(X, mean_prediction, label="Sklearn Mean Prediction")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Comparing Mean Predictions")

```



6.2 Exercises

6.2.1 Schonlau Example Function

- The Schonlau Example Function is based on sample points only (there is no analytical function description available):

```
X = np.linspace(start=0, stop=13, num=1_000).reshape(-1, 1)
X_train = np.array([1., 2., 3., 4., 12.]).reshape(-1,1)
y_train = np.array([0., -1.75, -2, -0.5, 5.])
```

- Describe the function.
- Compare the two models that were build using the `spotPython` and the `sklearn` surrogate.
- Note: Since there is no analytical function available, you might be interested in adding some points and describe the effects.

6.2.2 Forrester Example Function

- The Forrester Example Function is defined as follows:

$f(x) = (6x - 2)^2 \sin(12x - 4)$ for x in $[0, 1]$.

- Data points are generated as follows:

```
X = np.linspace(start=-0.5, stop=1.5, num=1_000).reshape(-1, 1)
X_train = np.array([0.0, 0.175, 0.225, 0.3, 0.35, 0.375, 0.5, 1]).reshape(-1, 1)
fun = analytical().fun_forrester
fun_control = {"sigma": 0.1,
               "seed": 123}
y = fun(X, fun_control=fun_control)
y_train = fun(X_train, fun_control=fun_control)
```

- Describe the function.
- Compare the two models that were build using the `spotPython` and the `sklearn` surrogate.
- Note: Modify the noise level ("`sigma`"), e.g., use a value of 0.2, and compare the two models.

```
fun_control = {"sigma": 0.2}
```

6.2.3 fun_runge Function (1-dim)

- The Runge function is defined as follows:

$f(x) = 1 / (1 + \sum(x_i))^2$

- Data points are generated as follows:

```
gen = spacefilling(1)
rng = np.random.RandomState(1)
lower = np.array([-10])
upper = np.array([10])
fun = analytical().fun_runge
fun_control = {"sigma": 0.025,
               "seed": 123}
X_train = gen.scipy_lhd(10, lower=lower, upper = upper).reshape(-1, 1)
y_train = fun(X, fun_control=fun_control)
X = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
y = fun(X, fun_control=fun_control)
```

- Describe the function.

- Compare the two models that were build using the `spotPython` and the `sklearn` surrogate.
- Note: Modify the noise level ("`sigma`"), e.g., use a value of 0.05, and compare the two models.

```
fun_control = {"sigma": 0.5}
```

6.2.4 fun_cubed (1-dim)

- The Cubed function is defined as follows:

```
np.sum(X[i]** 3)
```

- Data points are generated as follows:

```
gen = spacefilling(1)
rng = np.random.RandomState(1)
lower = np.array([-10])
upper = np.array([10])
fun = analytical().fun_cubed
fun_control = {"sigma": 0.025,
               "seed": 123}
X_train = gen.scipy_lhd(10, lower=lower, upper = upper).reshape(-1,1)
y_train = fun(X, fun_control=fun_control)
X = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
y = fun(X, fun_control=fun_control)
```

- Describe the function.
- Compare the two models that were build using the `spotPython` and the `sklearn` surrogate.
- Note: Modify the noise level ("`sigma`"), e.g., use a value of 0.05, and compare the two models.

```
fun_control = {"sigma": 0.05}
```

6.2.5 The Effect of Noise

How does the behavior of the `spotPython` fit changes when the argument `noise` is set to `True`, i.e.,

```
S = Kriging(name='kriging', seed=123, n_theta=1, noise=True)
```

is used?

7 Expected Improvement

7.1 Example: Spot and the 1-dim Sphere Function

```
import numpy as np
from math import inf
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
import matplotlib.pyplot as plt
```

7.1.1 The Objective Function: 1-dim Sphere

- The `spotPython` package provides several classes of objective functions.
- We will use an analytical objective function, i.e., a function that can be described by a (closed) formula:

$$f(x) = x^2$$

```
fun = analytical().fun_sphere
```

```
fun = analytical().fun_sphere
```

- The size of the `lower` bound vector determines the problem dimension.
- Here we will use `np.array([-1])`, i.e., a one-dim function.

TensorBoard

Similar to the one-dimensional case, which was introduced in Section [1.7](#), we can use TensorBoard to monitor the progress of the optimization. We will use the same code, only the prefix is different:

```

from spotPython.utils.file import get_experiment_name
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_spot_tensorboard_path

PREFIX = "07_Y"
experiment_name = get_experiment_name(prefix=PREFIX)
print(experiment_name)

fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    sigma=0,
    seed=123,)

```

07_Y_bartz08-2_2023-07-10_00-21-59

```

spot_1 = spot.Spot(fun=fun,
                   fun_evals = 25,
                   lower = np.array([-1]),
                   upper = np.array([1]),
                   design_control={"init_size": 10},
                   tolerance_x = np.sqrt(np.spacing(1)),
                   fun_control = fun_control,)

spot_1.run()

```

<spotPython.spot.spot.Spot at 0x1038fb700>

7.1.2 Results

```
spot_1.print_results()
```

```

min y: 2.135607331180881e-12
x0: -1.4613717292943917e-06

```

```
[['x0', -1.4613717292943917e-06]]
```

```
spot_1.plot_progress(log_y=True)
```

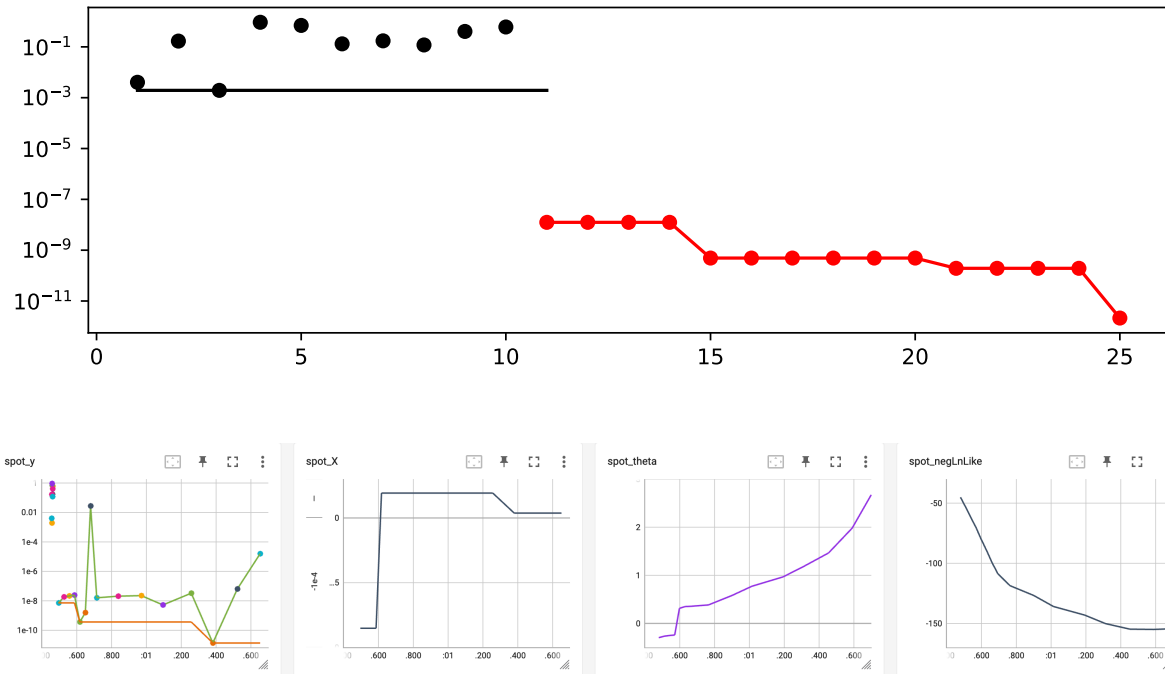


Figure 7.1: TensorBoard visualization of the spotPython optimization process and the surrogate model.

7.2 Same, but with EI as infill_criterion

```
PREFIX = "07_EI_ISO"
experiment_name = get_experiment_name(prefix=PREFIX)
print(experiment_name)
fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    sigma=0,
    seed=123,)
```

07_EI_ISO_bartz08-2_2023-07-10_00-22-02

```
spot_1_ei = spot.Spot(fun=fun,
    lower = np.array([-1]),
    upper = np.array([1]),
    fun_evals = 25,
```

```

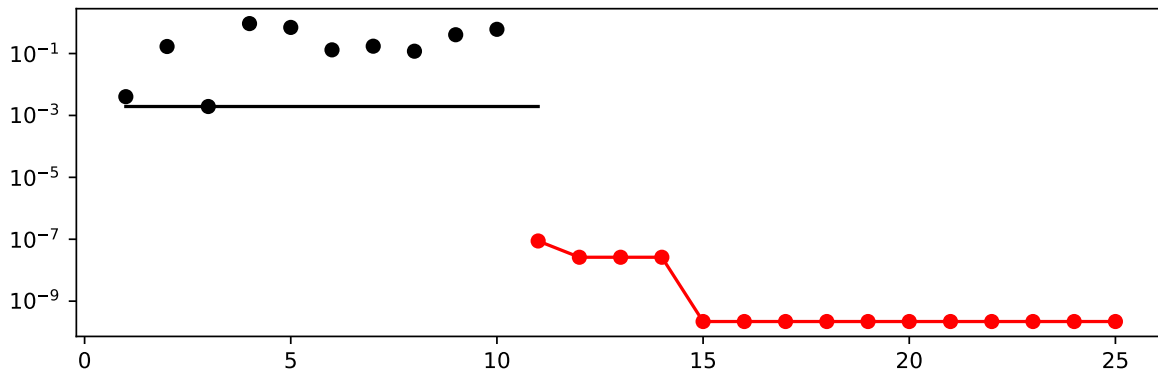
        tolerance_x = np.sqrt(np.spacing(1)),
        infill_criterion = "ei",
        design_control={"init_size": 10},
        fun_control = fun_control,)

spot_1_ei.run()

```

<spotPython.spot.spot.Spot at 0x29cd64d30>

```
spot_1_ei.plot_progress(log_y=True)
```



```
spot_1_ei.print_results()
```

```

min y: 2.1963022660037201e-10
x0: 1.4819926673245452e-05

```

```
[['x0', 1.4819926673245452e-05]]
```

7.3 Non-isotropic Kriging

```

PREFIX = "07_EI_NONISO"
experiment_name = get_experiment_name(prefix=PREFIX)
print(experiment_name)
fun_control = fun_control_init(

```

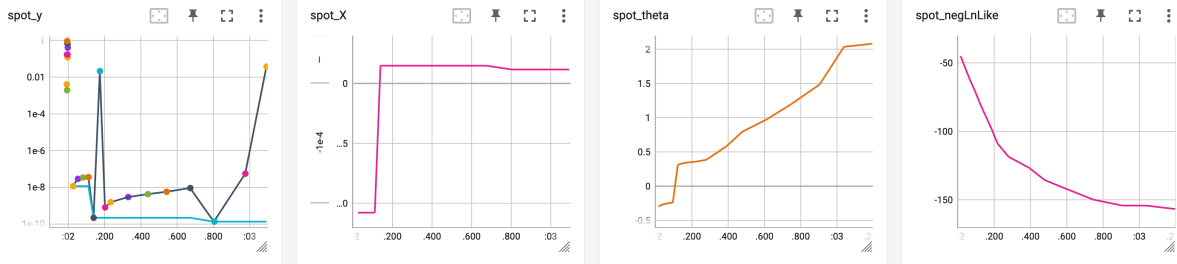


Figure 7.2: TensorBoard visualization of the spotPython optimization process and the surrogate model. Expected improvement, isotropic Kriging.

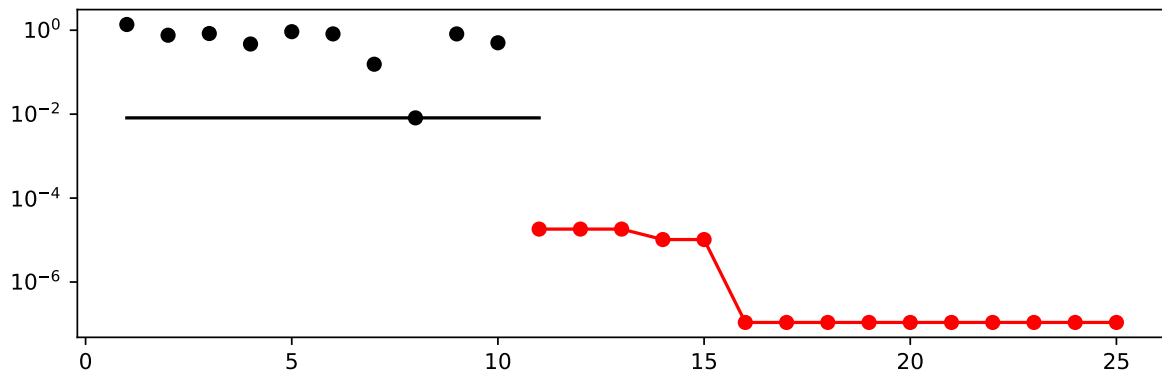
```
spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
sigma=0,
seed=123,)
```

07_EI_NONISO_bartz08-2_2023-07-10_00-22-04

```
spot_2_ei_noniso = spot.Spot(fun=fun,
    lower = np.array([-1, -1]),
    upper = np.array([1, 1]),
    fun_evals = 25,
    tolerance_x = np.sqrt(np.spacing(1)),
    infill_criterion = "ei",
    show_models=True,
    design_control={"init_size": 10},
    surrogate_control={"noise": False,
        "cod_type": "norm",
        "min_theta": -4,
        "max_theta": 3,
        "n_theta": 2,
        "model_fun_evals": 1000,
    },
    fun_control=fun_control,)
spot_2_ei_noniso.run()
```

<spotPython.spot.spot.Spot at 0x29cfde1d0>

```
spot_2_ei_noniso.plot_progress(log_y=True)
```



```
spot_2_ei_noniso.print_results()
```

```
min y: 1.088759927339735e-07
```

```
x0: -0.0002833471276146305
```

```
x1: 0.00016908695398081962
```

```
[['x0', -0.0002833471276146305], ['x1', 0.00016908695398081962]]
```

```
spot_2_ei_noniso.surrogate.plot()
```

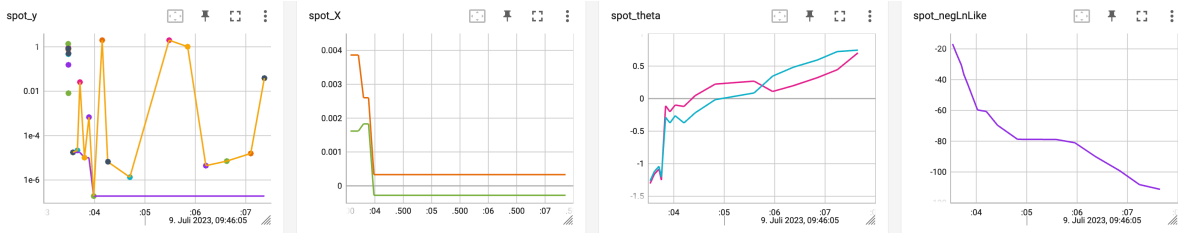
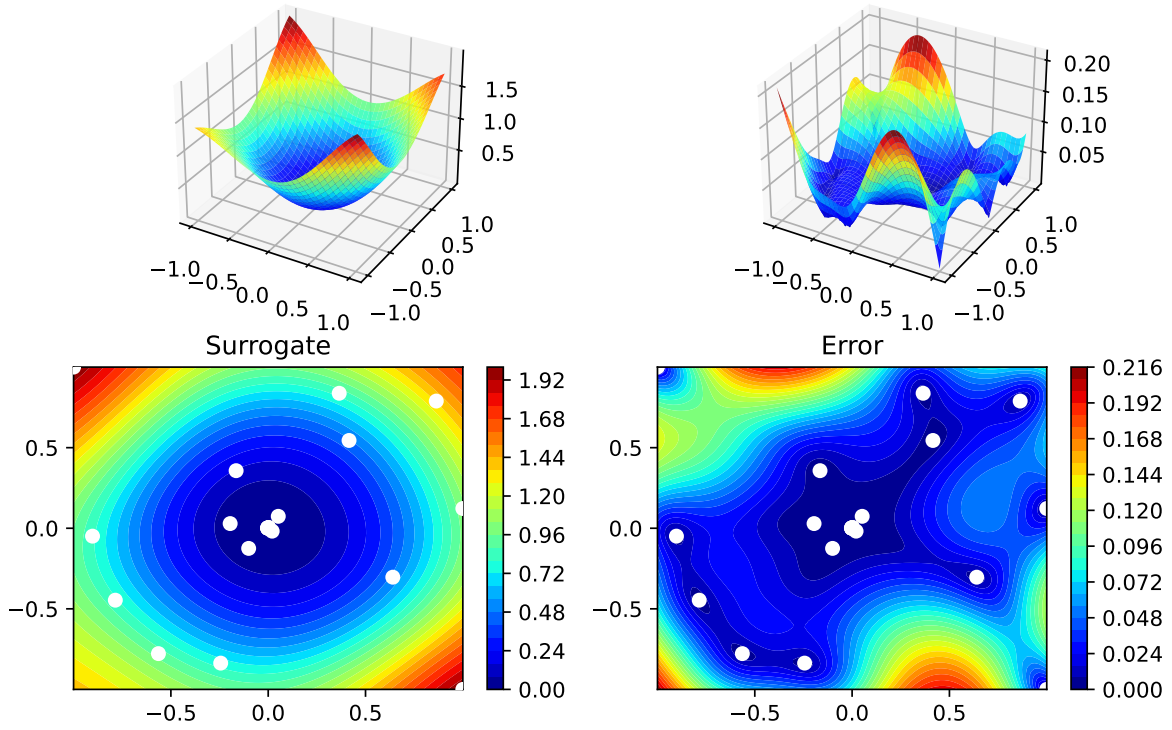



Figure 7.3: TensorBoard visualization of the spotPython optimization process and the surrogate model. Expected improvement, isotropic Kriging.

7.4 Using sklearn Surrogates

7.4.1 The spot Loop

The `spot` loop consists of the following steps:

1. Init: Build initial design X
2. Evaluate initial design on real objective f : $y = f(X)$

3. Build surrogate: $S = S(X, y)$
4. Optimize on surrogate: $X_0 = \text{optimize}(S)$
5. Evaluate on real objective: $y_0 = f(X_0)$
6. Impute (Infill) new points: $X = X \cup X_0, y = y \cup y_0$.
7. Got 3.

The **spot** loop is implemented in R as follows:

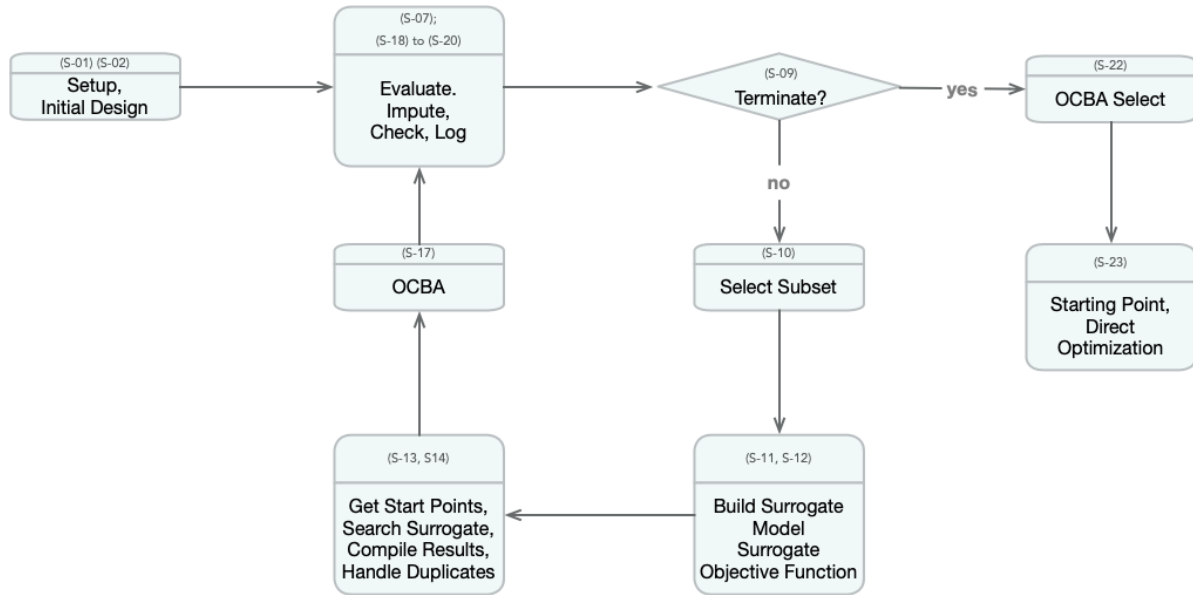


Figure 7.4: Visual representation of the model based search with SPOT. Taken from: Bartz-Beielstein, T., and Zaefferer, M. Hyperparameter tuning approaches. In Hyperparameter Tuning for Machine and Deep Learning with R - A Practical Guide, E. Bartz, T. Bartz-Beielstein, M. Zaefferer, and O. Mersmann, Eds. Springer, 2022, ch. 4, pp. 67–114.

7.4.2 spot: The Initial Model

7.4.2.1 Example: Modifying the initial design size

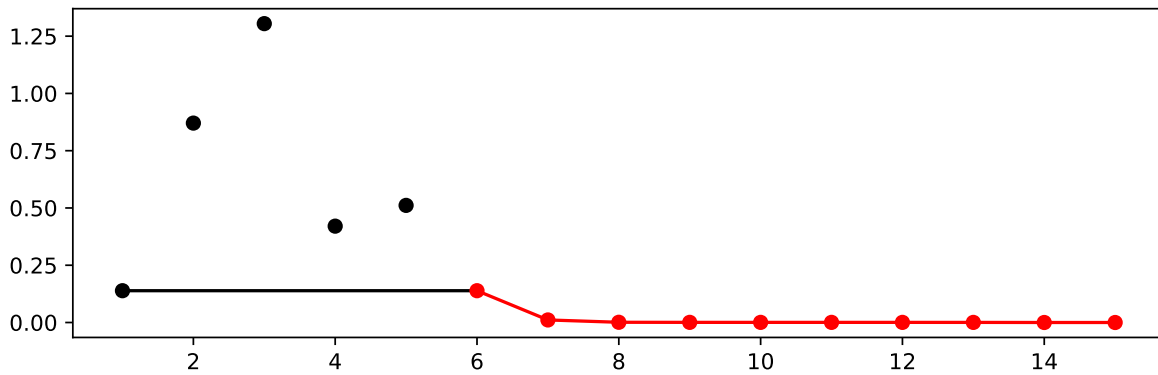
This is the “Example: Modifying the initial design size” from Chapter 4.5.1 in [bart21i].

```
spot_ei = spot.Spot(fun=fun,
                    lower = np.array([-1,-1]),
                    upper= np.array([1,1]),
                    design_control={"init_size": 5})
```

```
spot_ei.run()
```

```
<spotPython.spot.spot.Spot at 0x29ea18280>
```

```
spot_ei.plot_progress()
```



```
np.min(spot_1.y), np.min(spot_ei.y)
```

```
(2.135607331180881e-12, 1.881581967484049e-05)
```

7.4.3 Init: Build Initial Design

```
from spotPython.design.spacefilling import spacefilling
from spotPython.build.kriging import Kriging
from spotPython.fun.objectivefunctions import analytical
gen = spacefilling(2)
rng = np.random.RandomState(1)
lower = np.array([-5,-0])
upper = np.array([10,15])
fun = analytical().fun_branin

X = gen.scipy_lhd(10, lower=lower, upper = upper)
print(X)
y = fun(X, fun_control=fun_control)
print(y)
```

```

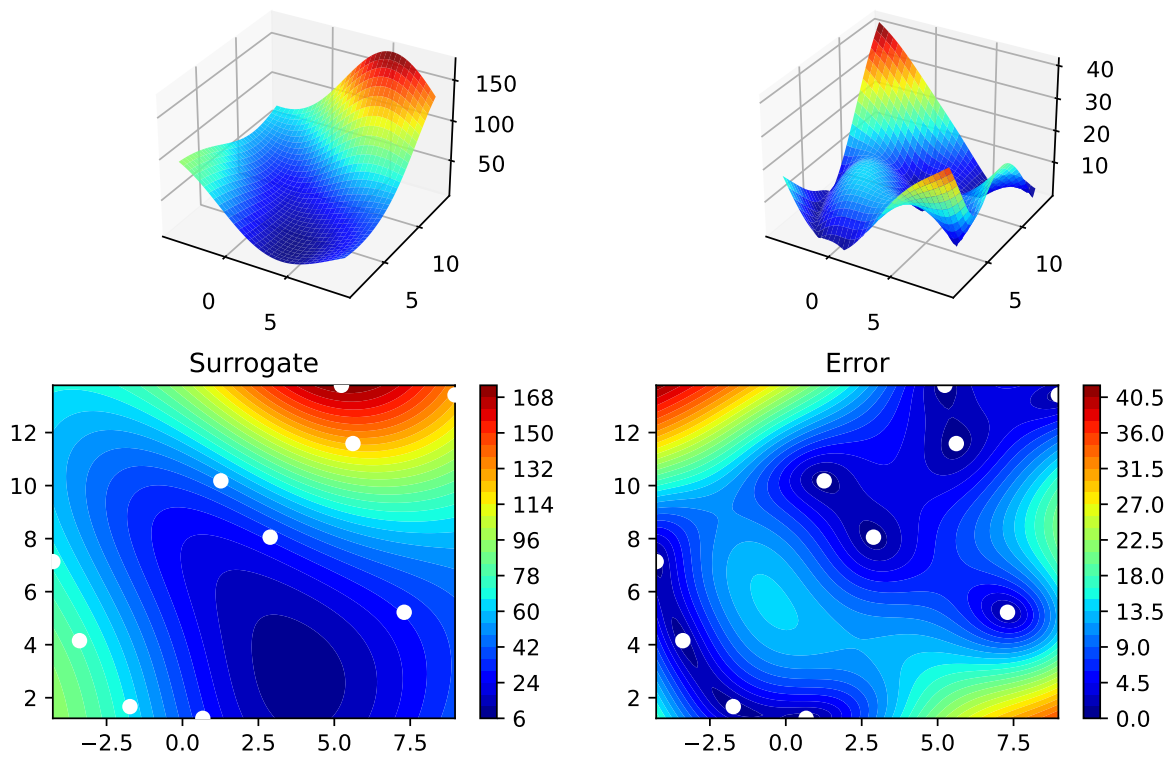
[[ 8.97647221 13.41926847]
 [ 0.66946019  1.22344228]
 [ 5.23614115 13.78185824]
 [ 5.6149825  11.5851384 ]
 [-1.72963184  1.66516096]
 [-4.26945568  7.1325531 ]
 [ 1.26363761 10.17935555]
 [ 2.88779942  8.05508969]
 [-3.39111089  4.15213772]
 [ 7.30131231  5.22275244]]
[128.95676449  31.73474356 172.89678121 126.71295908  64.34349975
 70.16178611  48.71407916  31.77322887  76.91788181  30.69410529]

```

```

S = Kriging(name='kriging', seed=123)
S.fit(X, y)
S.plot()

```



```

gen = spacefilling(2, seed=123)
X0 = gen.scipy_lhd(3)
gen = spacefilling(2, seed=345)
X1 = gen.scipy_lhd(3)
X2 = gen.scipy_lhd(3)
gen = spacefilling(2, seed=123)
X3 = gen.scipy_lhd(3)
X0, X1, X2, X3

```

```

(array([[0.77254938, 0.31539299],
        [0.59321338, 0.93854273],
        [0.27469803, 0.3959685 ]]),
 array([[0.78373509, 0.86811887],
        [0.06692621, 0.6058029 ],
        [0.41374778, 0.00525456]]),
 array([[0.121357  , 0.69043832],
        [0.41906219, 0.32838498],
        [0.86742658, 0.52910374]]),
 array([[0.77254938, 0.31539299],
        [0.59321338, 0.93854273],
        [0.27469803, 0.3959685 ]]))

```

7.4.4 Evaluate

7.4.5 Build Surrogate

7.4.6 A Simple Predictor

The code below shows how to use a simple model for prediction.

- Assume that only two (very costly) measurements are available:
 1. $f(0) = 0.5$
 2. $f(2) = 2.5$
- We are interested in the value at $x_0 = 1$, i.e., $f(x_0 = 1)$, but cannot run an additional, third experiment.

```

from sklearn import linear_model
X = np.array([[0], [2]])
y = np.array([0.5, 2.5])

```

```

S_lm = linear_model.LinearRegression()
S_lm = S_lm.fit(X, y)
X0 = np.array([[1]])
y0 = S_lm.predict(X0)
print(y0)

```

[1.5]

- Central Idea:
 - Evaluation of the surrogate model S_{lm} is much cheaper (or / and much faster) than running the real-world experiment f .

7.5 Gaussian Processes regression: basic introductory example

This example was taken from [scikit-learn](#). After fitting our model, we see that the hyperparameters of the kernel have been optimized. Now, we will use our kernel to compute the mean prediction of the full dataset and plot the 95% confidence interval.

```

import numpy as np
import matplotlib.pyplot as plt
import math as m
from sklearn.gaussian_process import GaussianProcessRegressor
from sklearn.gaussian_process.kernels import RBF

X = np.linspace(start=0, stop=10, num=1_000).reshape(-1, 1)
y = np.squeeze(X * np.sin(X))
rng = np.random.RandomState(1)
training_indices = rng.choice(np.arange(y.size), size=6, replace=False)
X_train, y_train = X[training_indices], y[training_indices]

kernel = 1 * RBF(length_scale=1.0, length_scale_bounds=(1e-2, 1e2))
gaussian_process = GaussianProcessRegressor(kernel=kernel, n_restarts_optimizer=9)
gaussian_process.fit(X_train, y_train)
gaussian_process.kernel_

mean_prediction, std_prediction = gaussian_process.predict(X, return_std=True)

plt.plot(X, y, label=r"$f(x) = x \sin(x)$", linestyle="dotted")
plt.scatter(X_train, y_train, label="Observations")
plt.plot(X, mean_prediction, label="Mean prediction")

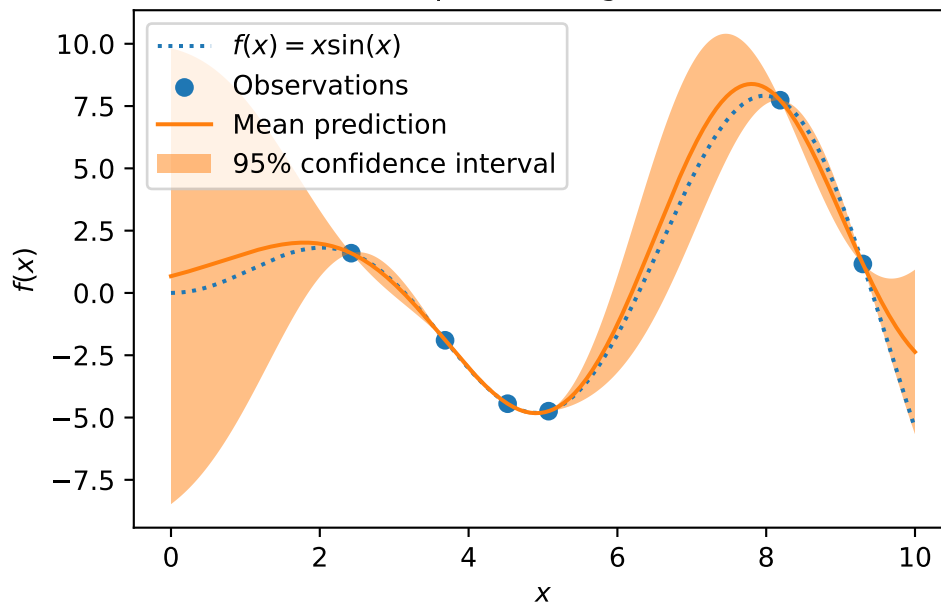
```

```

plt.fill_between(
    X.ravel(),
    mean_prediction - 1.96 * std_prediction,
    mean_prediction + 1.96 * std_prediction,
    alpha=0.5,
    label=r"95% confidence interval",
)
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("sk-learn Version: Gaussian process regression on noise-free dataset")

```

sk-learn Version: Gaussian process regression on noise-free dataset



```

from spotPython.build.kriging import Kriging
import numpy as np
import matplotlib.pyplot as plt
rng = np.random.RandomState(1)
X = np.linspace(start=0, stop=10, num=1_000).reshape(-1, 1)
y = np.squeeze(X * np.sin(X))
training_indices = rng.choice(np.arange(y.size), size=6, replace=False)
X_train, y_train = X[training_indices], y[training_indices]

```

```

S = Kriging(name='kriging', seed=123, log_level=50, cod_type="norm")
S.fit(X_train, y_train)

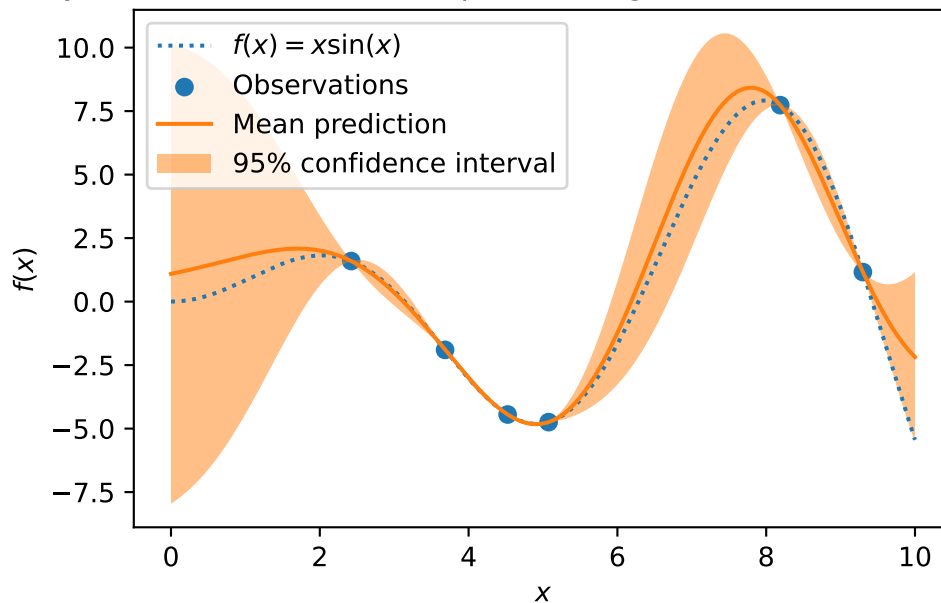
mean_prediction, std_prediction, ei = S.predict(X, return_val="all")

std_prediction

plt.plot(X, y, label=r"$f(x) = x \sin(x)$", linestyle="dotted")
plt.scatter(X_train, y_train, label="Observations")
plt.plot(X, mean_prediction, label="Mean prediction")
plt.fill_between(
    X.ravel(),
    mean_prediction - 1.96 * std_prediction,
    mean_prediction + 1.96 * std_prediction,
    alpha=0.5,
    label=r"95% confidence interval",
)
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("spotPython Version: Gaussian process regression on noise-free dataset")

```

spotPython Version: Gaussian process regression on noise-free dataset



7.6 The Surrogate: Using scikit-learn models

Default is the internal kriging surrogate.

```
S_0 = Kriging(name='kriging', seed=123)
```

Models from scikit-learn can be selected, e.g., Gaussian Process:

```
# Needed for the sklearn surrogates:
from sklearn.gaussian_process import GaussianProcessRegressor
from sklearn.gaussian_process.kernels import RBF
from sklearn.tree import DecisionTreeRegressor
from sklearn.ensemble import RandomForestRegressor
from sklearn import linear_model
from sklearn import tree
import pandas as pd
```

```
kernel = 1 * RBF(length_scale=1.0, length_scale_bounds=(1e-2, 1e2))
S_GP = GaussianProcessRegressor(kernel=kernel, n_restarts_optimizer=9)
```

- and many more:

```
S_Tree = DecisionTreeRegressor(random_state=0)
S_LM = linear_model.LinearRegression()
S_Ridge = linear_model.Ridge()
S_RF = RandomForestRegressor(max_depth=2, random_state=0)
```

- The scikit-learn GP model S_GP is selected.

```
S = S_GP
```

```
isinstance(S, GaussianProcessRegressor)
```

True

```
from spotPython.fun.objectivefunctions import analytical
fun = analytical().fun_branin
lower = np.array([-5,-0])
upper = np.array([10,15])
design_control={"init_size": 5}
```

```

surrogate_control={
    "infill_criterion": None,
    "n_points": 1,
}
spot_GP = spot.Spot(fun=fun, lower = lower, upper= upper, surrogate=S,
    fun_evals = 15, noise = False, log_level = 50,
    design_control=design_control,
    surrogate_control=surrogate_control)

spot_GP.run()

```

<spotPython.spot.spot.Spot at 0x29ee8bcd0>

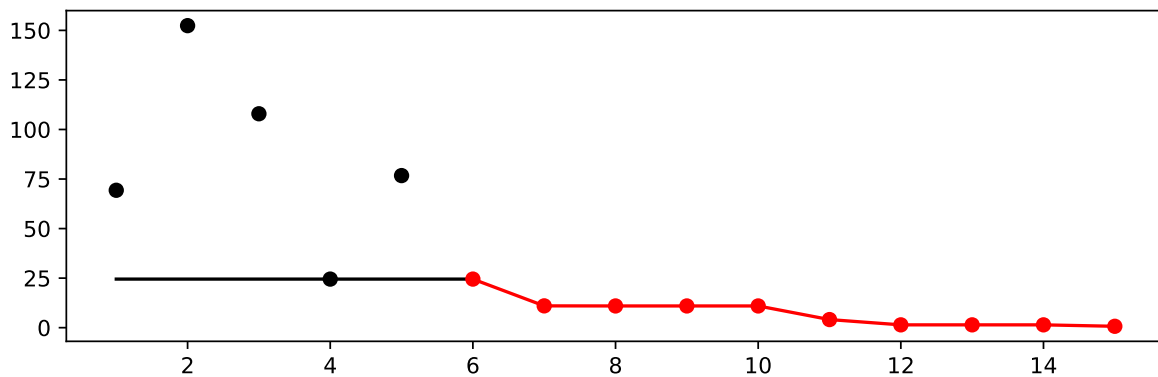
```
spot_GP.y
```

```

array([ 69.32459936, 152.38491454, 107.92560483,  24.51465459,
        76.73500031,  86.304256   ,  11.00307816,  10.96066519,
        16.06668258,  24.08432082,   4.08948415,   1.42303775,
         1.47359526,  16.04703294,   0.6989341  ])

```

```
spot_GP.plot_progress()
```



```
spot_GP.print_results()
```

```

min y: 0.6989341031319167
x0: 3.358292789592623
x1: 2.3886120108545597

```

```
[['x0', 3.358292789592623], ['x1', 2.3886120108545597]]
```

7.7 Additional Examples

```
# Needed for the sklearn surrogates:
from sklearn.gaussian_process import GaussianProcessRegressor
from sklearn.gaussian_process.kernels import RBF
from sklearn.tree import DecisionTreeRegressor
from sklearn.ensemble import RandomForestRegressor
from sklearn import linear_model
from sklearn import tree
import pandas as pd

kernel = 1 * RBF(length_scale=1.0, length_scale_bounds=(1e-2, 1e2))
S_GP = GaussianProcessRegressor(kernel=kernel, n_restarts_optimizer=9)

from spotPython.build.kriging import Kriging
import numpy as np
import spotPython
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot

S_K = Kriging(name='kriging',
              seed=123,
              log_level=50,
              infill_criterion = "y",
              n_theta=1,
              noise=False,
              cod_type="norm")
fun = analytical().fun_sphere
lower = np.array([-1,-1])
upper = np.array([1,1])

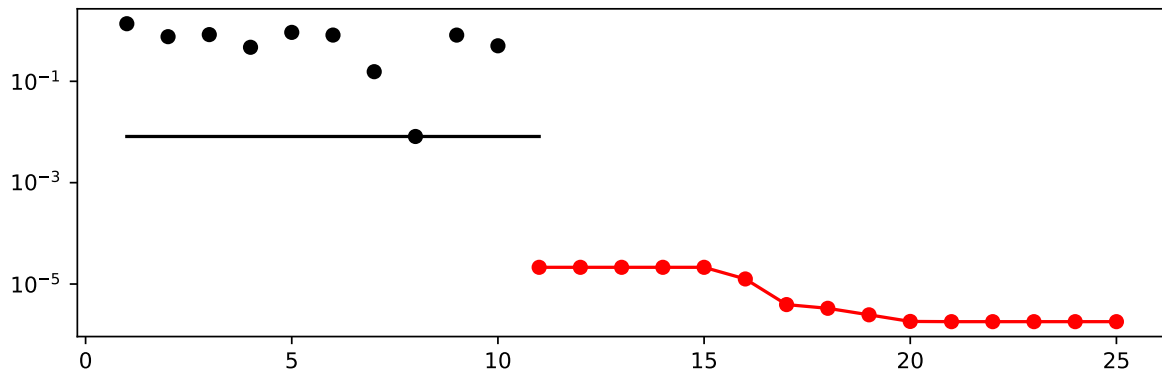
design_control={"init_size": 10}
surrogate_control={
    "n_points": 1,
}
spot_S_K = spot.Spot(fun=fun,
                    lower = lower,
```

```
upper= upper,  
surrogate=S_K,  
fun_evals = 25,  
noise = False,  
log_level = 50,  
design_control=design_control,  
surrogate_control=surrogate_control)
```

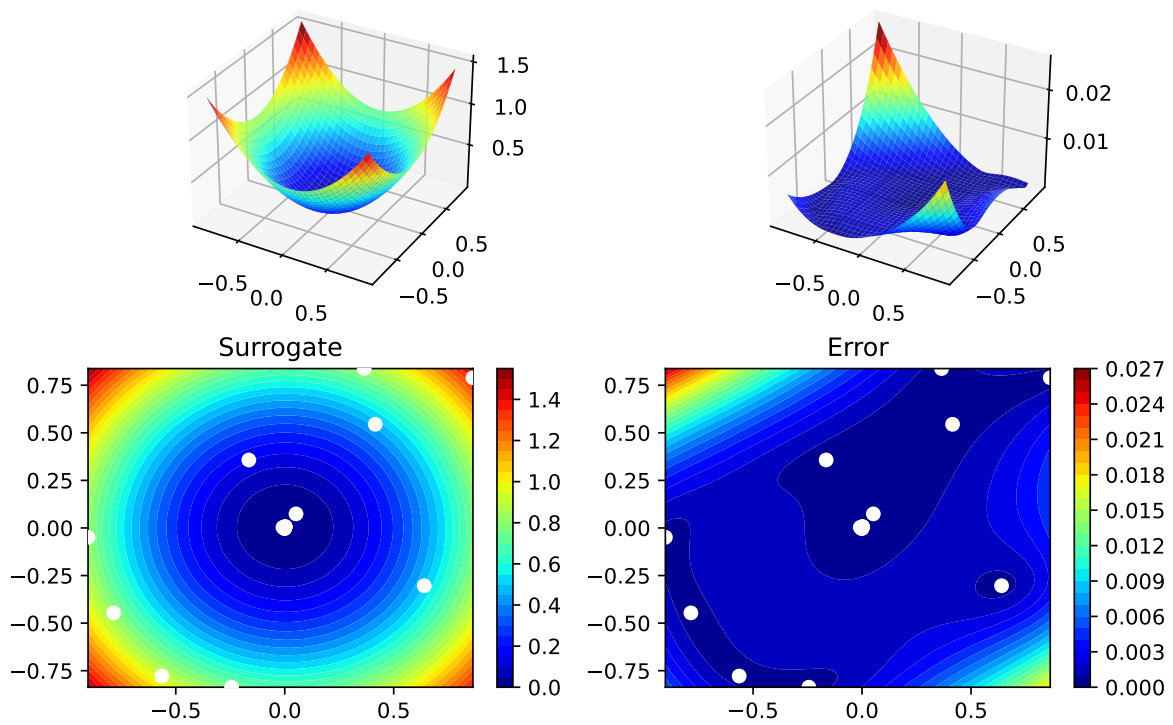
```
spot_S_K.run()
```

```
<spotPython.spot.spot.Spot at 0x2af8bbb50>
```

```
spot_S_K.plot_progress(log_y=True)
```



```
spot_S_K.surrogate.plot()
```



```
spot_S_K.print_results()
```

```
min y: 1.809224307539433e-06
x0: -0.001330101474082372
x1: 0.0002001358942901893
```

```
[['x0', -0.001330101474082372], ['x1', 0.0002001358942901893]]
```

7.7.1 Optimize on Surrogate

7.7.2 Evaluate on Real Objective

7.7.3 Impute / Infill new Points

7.8 Tests

```
import numpy as np
from spotPython.spot import spot
from spotPython.fun.objectivefunctions import analytical

fun_sphere = analytical().fun_sphere
spot_1 = spot.Spot(
    fun=fun_sphere,
    lower=np.array([-1, -1]),
    upper=np.array([1, 1]),
    n_points = 2
)

# (S-2) Initial Design:
spot_1.X = spot_1.design.scipy_lhd(
    spot_1.design_control["init_size"], lower=spot_1.lower, upper=spot_1.upper
)
print(spot_1.X)

# (S-3): Eval initial design:
spot_1.y = spot_1.fun(spot_1.X)
print(spot_1.y)

spot_1.surrogate.fit(spot_1.X, spot_1.y)
X0 = spot_1.suggest_new_X()
print(X0)
assert X0.size == spot_1.n_points * spot_1.k
```

```
[[ 0.86352963  0.7892358 ]
 [-0.24407197 -0.83687436]
 [ 0.36481882  0.8375811 ]
 [ 0.415331    0.54468512]
 [-0.56395091 -0.77797854]
 [-0.90259409 -0.04899292]]
```

```

[-0.16484832  0.35724741]
[ 0.05170659  0.07401196]
[-0.78548145 -0.44638164]
[ 0.64017497 -0.30363301]]
[1.36857656 0.75992983 0.83463487 0.46918172 0.92329124 0.8170764
 0.15480068 0.00815134 0.81623768 0.502017  ]
[[0.00151305 0.00405727]
 [0.00151305 0.00405727]]

```

7.9 EI: The Famous Schonlau Example

```

X_train0 = np.array([1, 2, 3, 4, 12]).reshape(-1,1)
X_train = np.linspace(start=0, stop=10, num=5).reshape(-1, 1)

from spotPython.build.kriging import Kriging
import numpy as np
import matplotlib.pyplot as plt

X_train = np.array([1., 2., 3., 4., 12.]).reshape(-1,1)
y_train = np.array([0., -1.75, -2, -0.5, 5.])

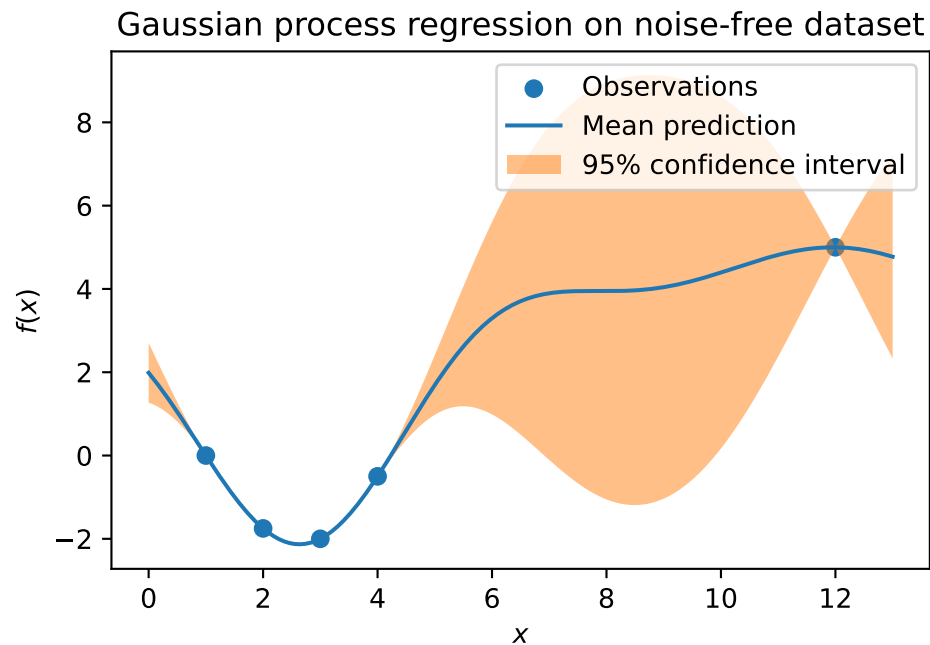
S = Kriging(name='kriging', seed=123, log_level=50, n_theta=1, noise=False, cod_type="non")
S.fit(X_train, y_train)

X = np.linspace(start=0, stop=13, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S.predict(X, return_val="all")

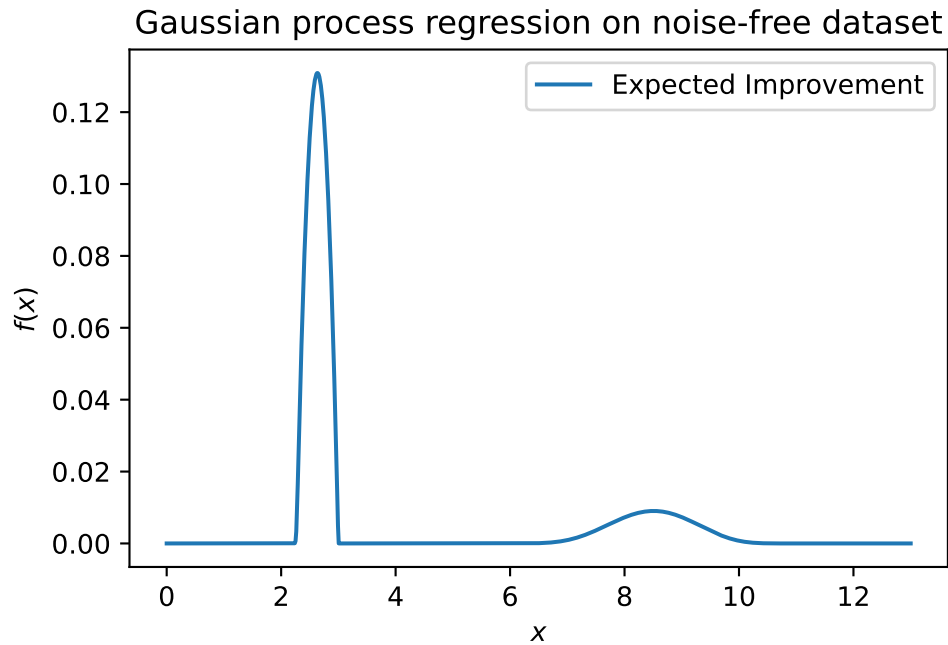
plt.scatter(X_train, y_train, label="Observations")
plt.plot(X, mean_prediction, label="Mean prediction")
if True:
    plt.fill_between(
        X.ravel(),
        mean_prediction - 2 * std_prediction,
        mean_prediction + 2 * std_prediction,
        alpha=0.5,
        label=r"95% confidence interval",
    )
plt.legend()
plt.xlabel("$x$")

```

```
plt.ylabel("$f(x)$")
_ = plt.title("Gaussian process regression on noise-free dataset")
```



```
#plt.plot(X, y, label=r"$f(x) = x \sin(x)$", linestyle="dotted")
# plt.scatter(X_train, y_train, label="Observations")
plt.plot(X, -ei, label="Expected Improvement")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Gaussian process regression on noise-free dataset")
```

S.log

```
{'negLnLike': array([1.20788205]),
 'theta': array([1.09275997]),
 'p': [],
 'Lambda': []}
```

7.10 EI: The Forrester Example

```
from spotPython.build.kriging import Kriging
import numpy as np
import matplotlib.pyplot as plt
import spotPython
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot

# exact x locations are unknown:
X_train = np.array([0.0, 0.175, 0.225, 0.3, 0.35, 0.375, 0.5, 1]).reshape(-1,1)
```

```

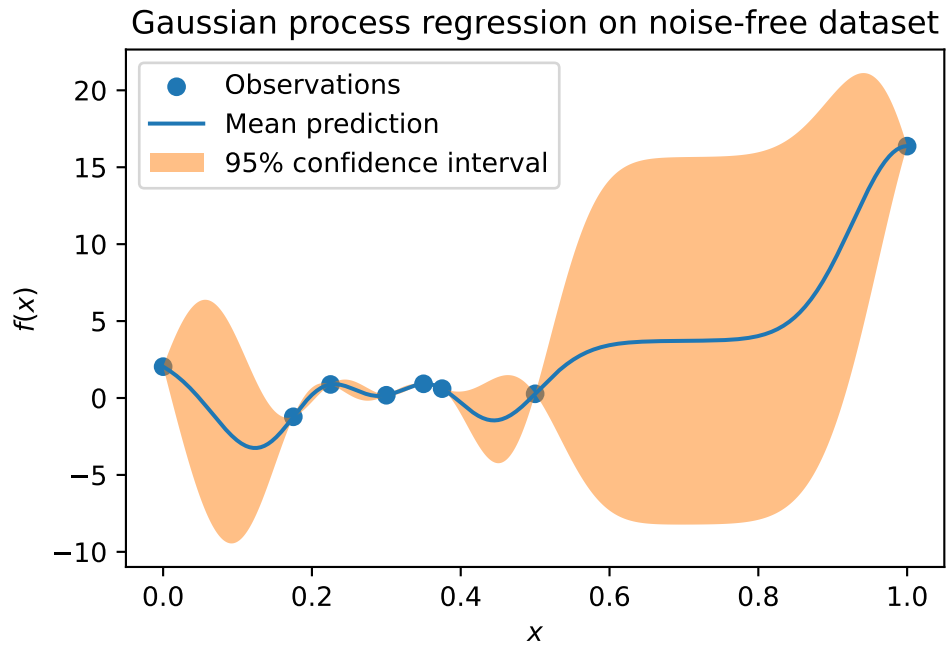
fun = analytical().fun_forrester
fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    sigma=1.0,
    seed=123,)
y_train = fun(X_train, fun_control=fun_control)

S = Kriging(name='kriging', seed=123, log_level=50, n_theta=1, noise=False, cod_type="non")
S.fit(X_train, y_train)

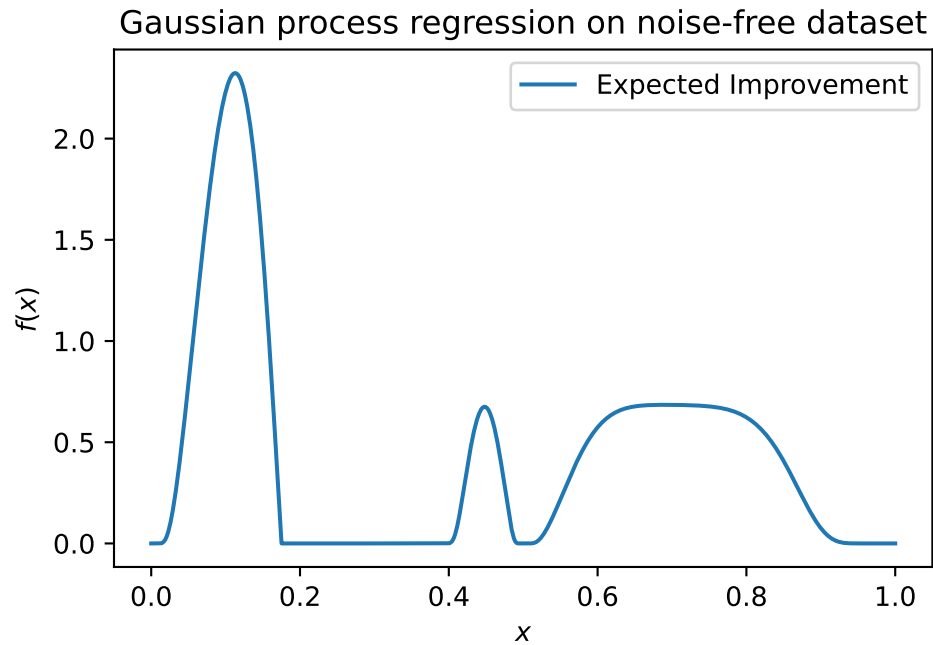
X = np.linspace(start=0, stop=1, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S.predict(X, return_val="all")

plt.scatter(X_train, y_train, label="Observations")
plt.plot(X, mean_prediction, label="Mean prediction")
if True:
    plt.fill_between(
        X.ravel(),
        mean_prediction - 2 * std_prediction,
        mean_prediction + 2 * std_prediction,
        alpha=0.5,
        label=r"95% confidence interval",
    )
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Gaussian process regression on noise-free dataset")

```



```
#plt.plot(X, y, label=r"$f(x) = x \sin(x)$", linestyle="dotted")
# plt.scatter(X_train, y_train, label="Observations")
plt.plot(X, -ei, label="Expected Improvement")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Gaussian process regression on noise-free dataset")
```



7.11 Noise

```
import numpy as np
import spotPython
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
from spotPython.design.spacefilling import spacefilling
from spotPython.build.kriging import Kriging
import matplotlib.pyplot as plt

gen = spacefilling(1)
rng = np.random.RandomState(1)
lower = np.array([-10])
upper = np.array([10])
fun = analytical().fun_sphere
fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    sigma=2.0,
    seed=123,)
X = gen.scipy_lhd(10, lower=lower, upper = upper)
```

```

print(X)
y = fun(X, fun_control=fun_control)
print(y)
y.shape
X_train = X.reshape(-1,1)
y_train = y

S = Kriging(name='kriging',
            seed=123,
            log_level=50,
            n_theta=1,
            noise=False)
S.fit(X_train, y_train)

X_axis = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S.predict(X_axis, return_val="all")

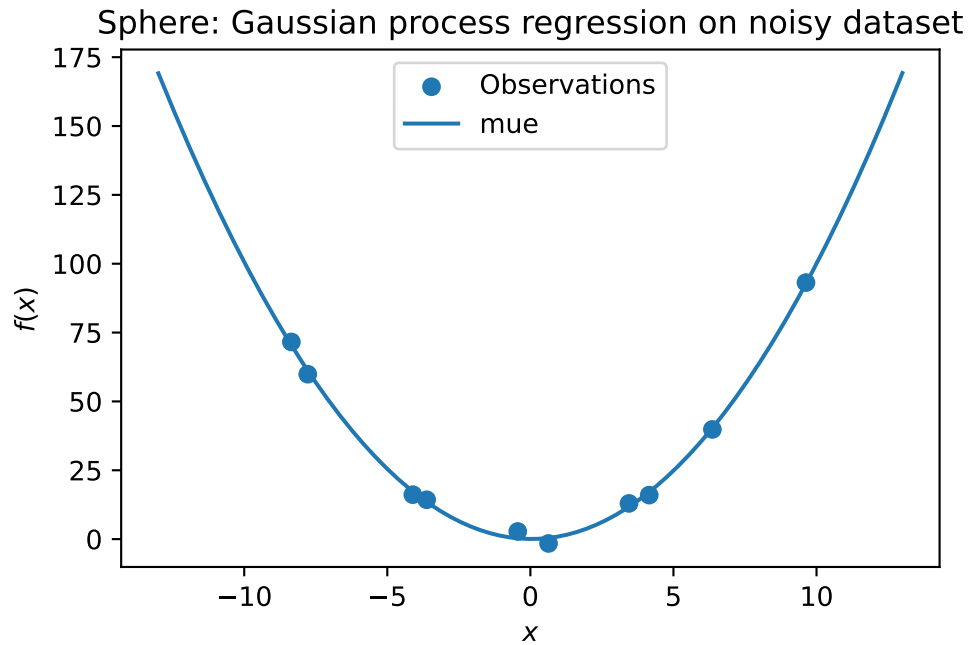
#plt.plot(X, y, label=r"$f(x) = x \sin(x)$", linestyle="dotted")
plt.scatter(X_train, y_train, label="Observations")
#plt.plot(X, ei, label="Expected Improvement")
plt.plot(X_axis, mean_prediction, label="mue")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Sphere: Gaussian process regression on noisy dataset")

```

```

[[ 0.63529627]
 [-4.10764204]
 [-0.44071975]
 [ 9.63125638]
 [-8.3518118 ]
 [-3.62418901]
 [ 4.15331    ]
 [ 3.4468512 ]
 [ 6.36049088]
 [-7.77978539]]
[-1.57464135 16.13714981  2.77008442 93.14904827 71.59322218 14.28895359
 15.9770567  12.96468767 39.82265329 59.88028242]

```



```
S.log
```

```
{'negLnLike': array([25.26601608]),
 'theta': array([-1.98024606]),
 'p': [],
 'Lambda': []}
```

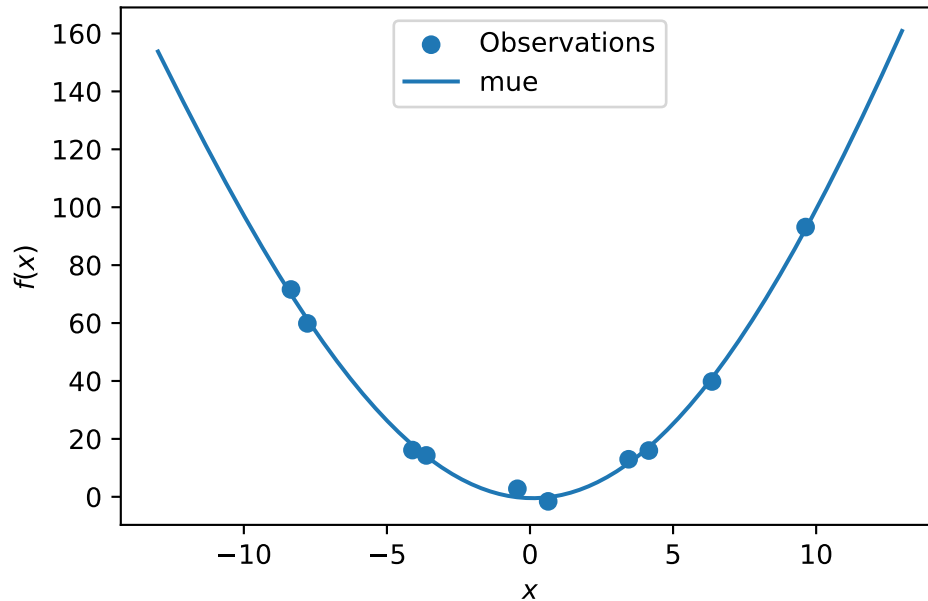
```
S = Kriging(name='kriging',
            seed=123,
            log_level=50,
            n_theta=1,
            noise=True)
S.fit(X_train, y_train)
```

```
X_axis = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S.predict(X_axis, return_val="all")
```

```
#plt.plot(X, y, label=r"$f(x) = x \sin(x)$", linestyle="dotted")
plt.scatter(X_train, y_train, label="Observations")
#plt.plot(X, ei, label="Expected Improvement")
plt.plot(X_axis, mean_prediction, label="mue")
```

```
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Sphere: Gaussian process regression with nugget on noisy dataset")
```

Sphere: Gaussian process regression with nugget on noisy dataset



S.log

```
{'negLnLike': array([21.82530943]),
 'theta': array([-0.41935831]),
 'p': [],
 'Lambda': array([5.20850895e-05])}
```

7.12 Cubic Function

```
import numpy as np
import spotPython
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
from spotPython.design.spacefilling import spacefilling
```

```

from spotPython.build.kriging import Kriging
import matplotlib.pyplot as plt

gen = spacefilling(1)
rng = np.random.RandomState(1)
lower = np.array([-10])
upper = np.array([10])
fun = analytical().fun_cubed
fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    sigma=10.0,
    seed=123,)

X = gen.scipy_lhd(10, lower=lower, upper = upper)
print(X)
y = fun(X, fun_control=fun_control)
print(y)
y.shape
X_train = X.reshape(-1,1)
y_train = y

S = Kriging(name='kriging', seed=123, log_level=50, n_theta=1, noise=False)
S.fit(X_train, y_train)

X_axis = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S.predict(X_axis, return_val="all")

plt.scatter(X_train, y_train, label="Observations")
#plt.plot(X, ei, label="Expected Improvement")
plt.plot(X_axis, mean_prediction, label="mue")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Cubed: Gaussian process regression on noisy dataset")

```

```

[[ 0.63529627]
 [-4.10764204]
 [-0.44071975]
 [ 9.63125638]
 [-8.3518118 ]
 [-3.62418901]
 [ 4.15331    ]

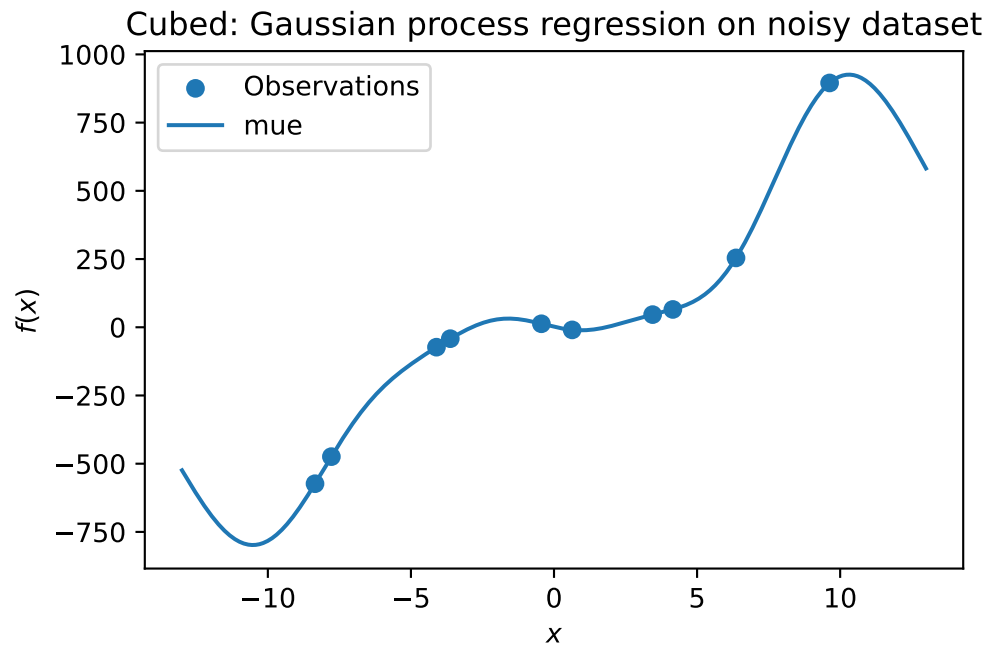
```



```

[ 3.4468512 ]
[ 6.36049088]
[-7.77978539]
[ -9.63480707 -72.98497325  12.7936499   895.34567477 -573.35961837
 -41.83176425  65.27989461  46.37081417  254.1530734  -474.09587355]

```



```

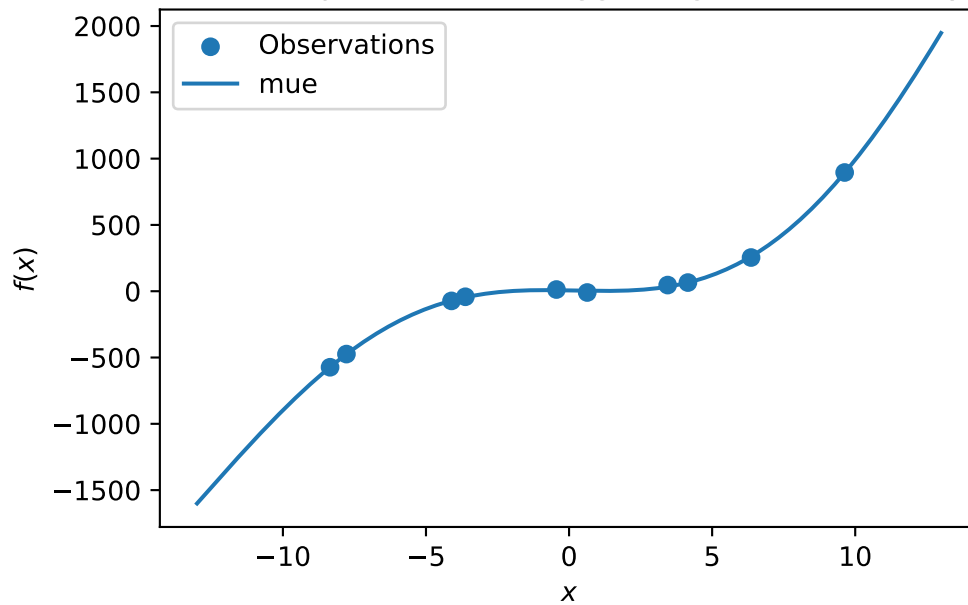
S = Kriging(name='kriging', seed=123, log_level=0, n_theta=1, noise=True)
S.fit(X_train, y_train)

X_axis = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S.predict(X_axis, return_val="all")

plt.scatter(X_train, y_train, label="Observations")
#plt.plot(X, ei, label="Expected Improvement")
plt.plot(X_axis, mean_prediction, label="mue")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Cubed: Gaussian process with nugget regression on noisy dataset")

```

Cubed: Gaussian process with nugget regression on noisy dataset



```
import numpy as np
import spotPython
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
from spotPython.design.spacefilling import spacefilling
from spotPython.build.kriging import Kriging
import matplotlib.pyplot as plt

gen = spacefilling(1)
rng = np.random.RandomState(1)
lower = np.array([-10])
upper = np.array([10])
fun = analytical().fun_runge
fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    sigma=0.25,
    seed=123,)

X = gen.scipy_lhd(10, lower=lower, upper = upper)
print(X)
y = fun(X, fun_control=fun_control)
```

```

print(y)
y.shape
X_train = X.reshape(-1,1)
y_train = y

S = Kriging(name='kriging', seed=123, log_level=50, n_theta=1, noise=False)
S.fit(X_train, y_train)

X_axis = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S.predict(X_axis, return_val="all")

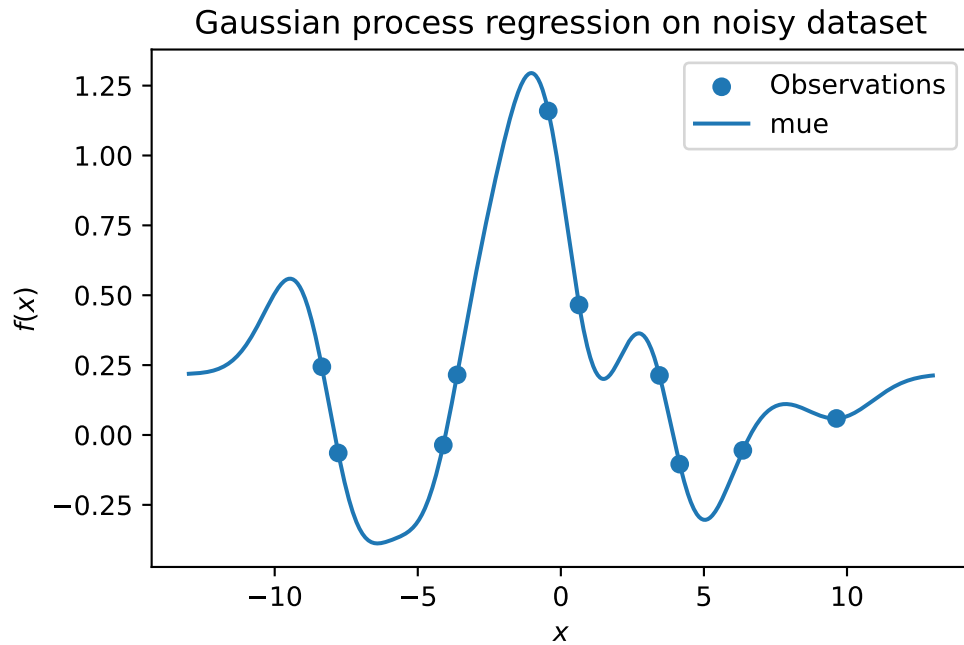
plt.scatter(X_train, y_train, label="Observations")
#plt.plot(X, ei, label="Expected Improvement")
plt.plot(X_axis, mean_prediction, label="mue")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Gaussian process regression on noisy dataset")

```

```

[[ 0.63529627]
 [-4.10764204]
 [-0.44071975]
 [ 9.63125638]
 [-8.3518118 ]
 [-3.62418901]
 [ 4.15331   ]
 [ 3.4468512 ]
 [ 6.36049088]
 [-7.77978539]]
[ 0.46517267 -0.03599548  1.15933822  0.05915901  0.24419145  0.21502359
 -0.10432134  0.21312309 -0.05502681 -0.06434374]

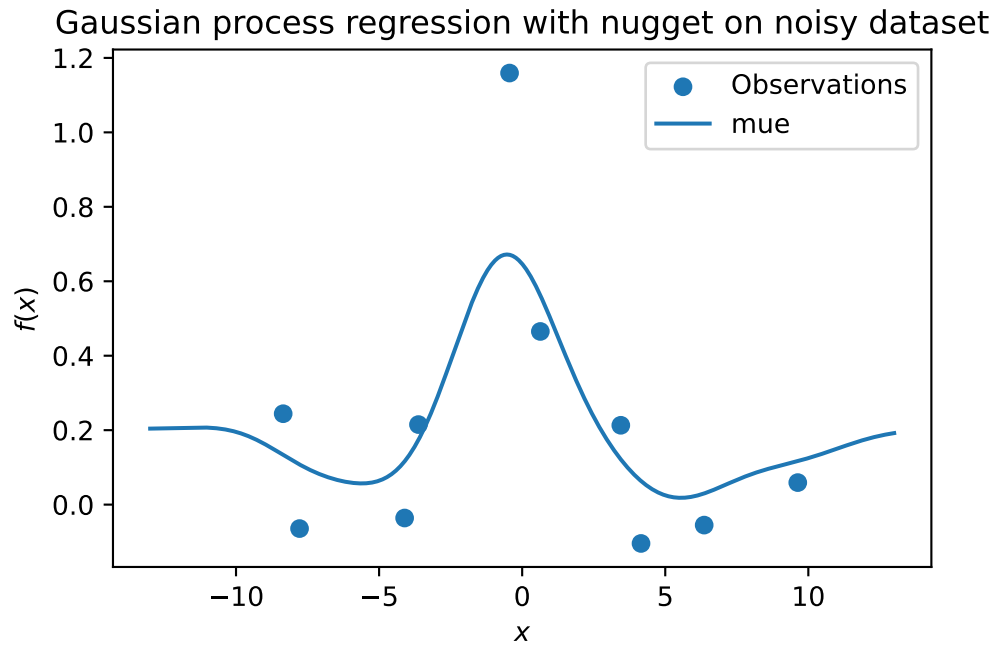
```



```
S = Kriging(name='kriging',
            seed=123,
            log_level=50,
            n_theta=1,
            noise=True)
S.fit(X_train, y_train)

X_axis = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S.predict(X_axis, return_val="all")

plt.scatter(X_train, y_train, label="Observations")
#plt.plot(X, ei, label="Expected Improvement")
plt.plot(X_axis, mean_prediction, label="mue")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Gaussian process regression with nugget on noisy dataset")
```



7.13 Factors

```
["num"] * 3
```

```
['num', 'num', 'num']
```

```
from spotPython.design.spacefilling import spacefilling
from spotPython.build.kriging import Kriging
from spotPython.fun.objectivefunctions import analytical
import numpy as np
```

```
gen = spacefilling(2)
n = 30
rng = np.random.RandomState(1)
lower = np.array([-5,-0])
upper = np.array([10,15])
fun = analytical().fun_branin_factor
#fun = analytical(sigma=0).fun_sphere
```

```

X0 = gen.scipy_lhd(n, lower=lower, upper = upper)
X1 = np.random.randint(low=1, high=3, size=(n,))
X = np.c_[X0, X1]
y = fun(X)
S = Kriging(name='kriging', seed=123, log_level=50, n_theta=3, noise=False, var_type=["nu
S.fit(X, y)
Sf = Kriging(name='kriging', seed=123, log_level=50, n_theta=3, noise=False, var_type=["n
Sf.fit(X, y)
n = 50
X0 = gen.scipy_lhd(n, lower=lower, upper = upper)
X1 = np.random.randint(low=1, high=3, size=(n,))
X = np.c_[X0, X1]
y = fun(X)
s=np.sum(np.abs(S.predict(X)[0] - y))
sf=np.sum(np.abs(Sf.predict(X)[0] - y))
sf - s

```

-40.513457642582125

```
# vars(S)
```

```
# vars(Sf)
```

8 Hyperparameter Tuning and Noise

This chapter demonstrates how noisy functions can be handled by Spot.

8.1 Example: Spot and the Noisy Sphere Function

```
import numpy as np
from math import inf
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
import matplotlib.pyplot as plt
from spotPython.utils.file import get_experiment_name
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_spot_tensorboard_path

PREFIX = "08"
experiment_name = get_experiment_name(prefix=PREFIX)
print(experiment_name)
```

08_bartz08-2_2023-07-10_00-22-44

8.1.1 The Objective Function: Noisy Sphere

- The `spotPython` package provides several classes of objective functions.
- We will use an analytical objective function with noise, i.e., a function that can be described by a (closed) formula:

$$f(x) = x^2 + \epsilon$$

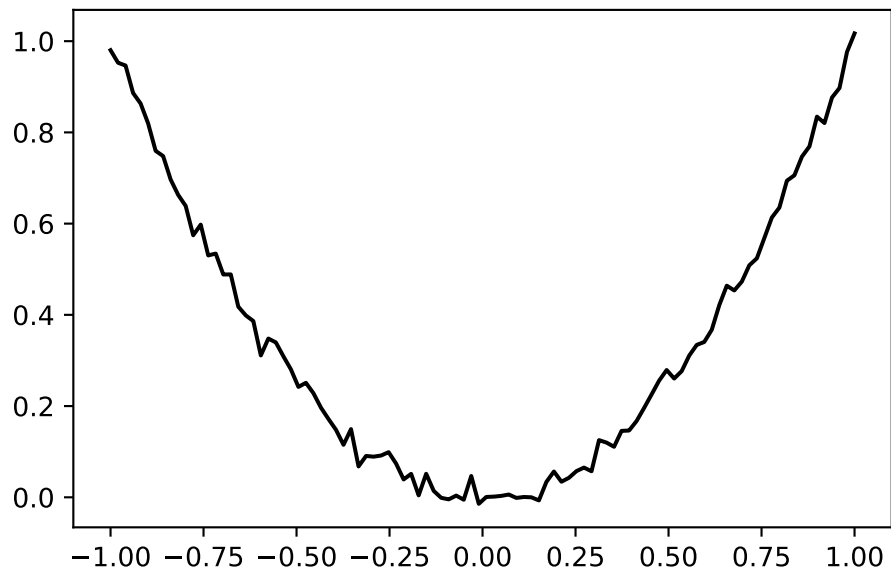
- Since `sigma` is set to 0.1, noise is added to the function:

```
fun = analytical().fun_sphere
fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
```

```
sigma=0.02,
seed=123,)
```

- A plot illustrates the noise:

```
x = np.linspace(-1,1,100).reshape(-1,1)
y = fun(x, fun_control=fun_control)
plt.figure()
plt.plot(x,y, "k")
plt.show()
```



Spot is adopted as follows to cope with noisy functions:

1. `fun_repeats` is set to a value larger than 1 (here: 2)
2. `noise` is set to `true`. Therefore, a nugget (`Lambda`) term is added to the correlation matrix
3. `init size` (of the `design_control` dictionary) is set to a value larger than 1 (here: 2)

```
spot_1_noisy = spot.Spot(fun=fun,
    lower = np.array([-1]),
    upper = np.array([1]),
    fun_evals = 20,
    fun_repeats = 2,
```

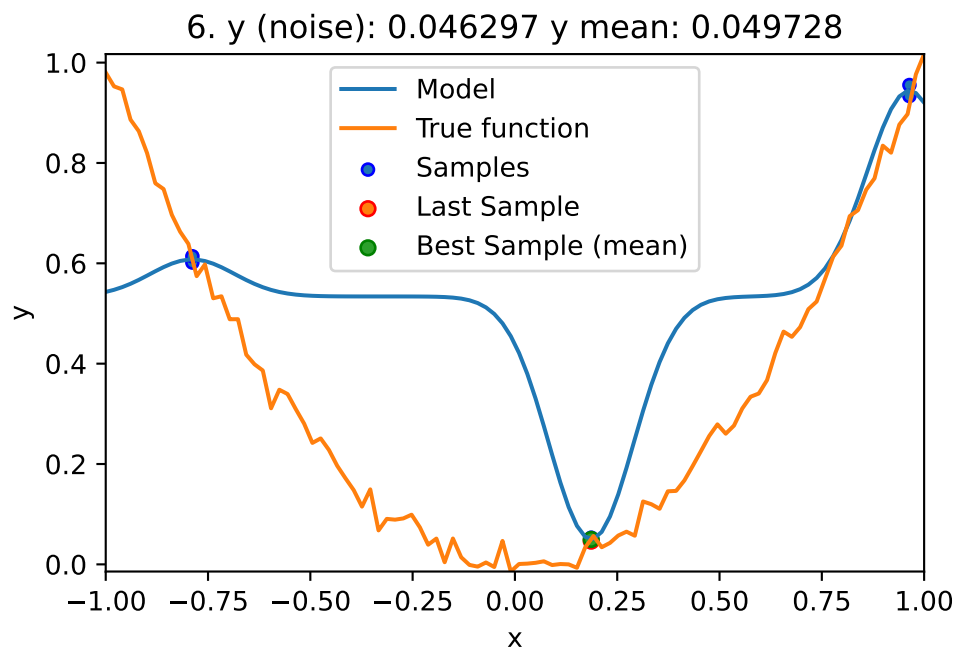


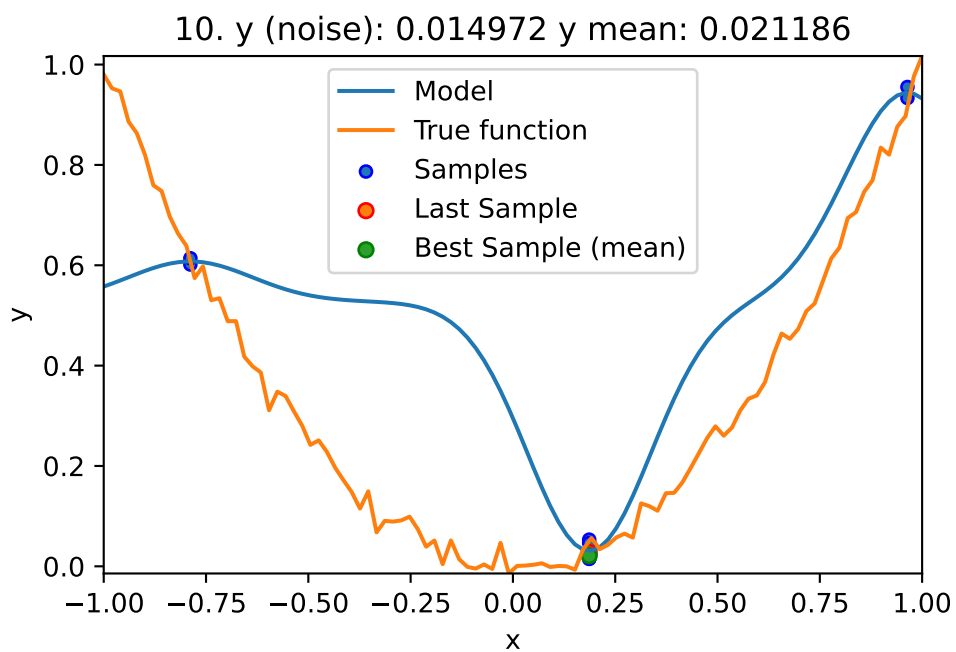
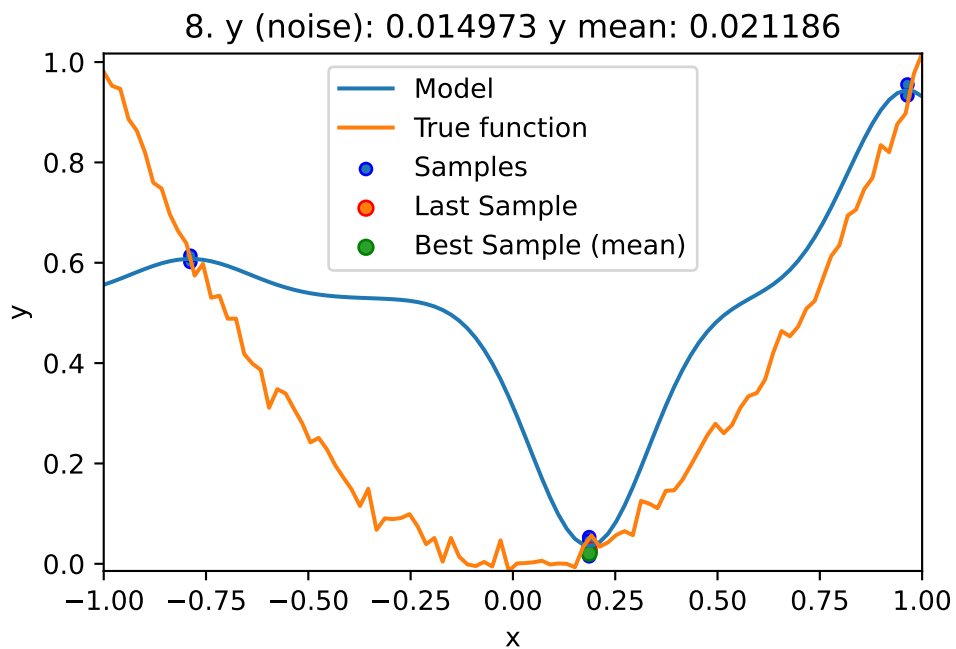
```

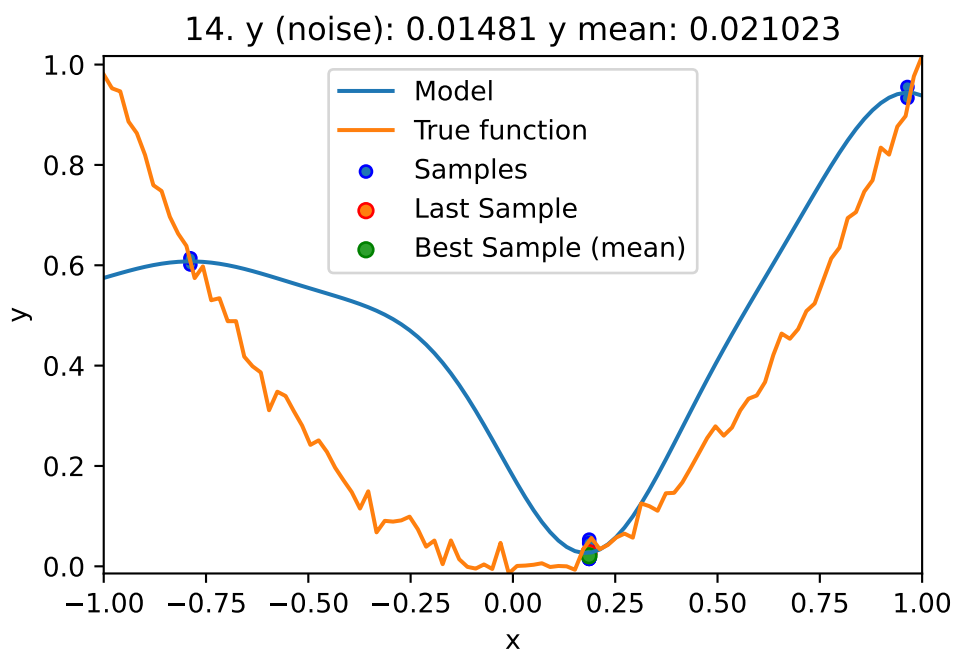
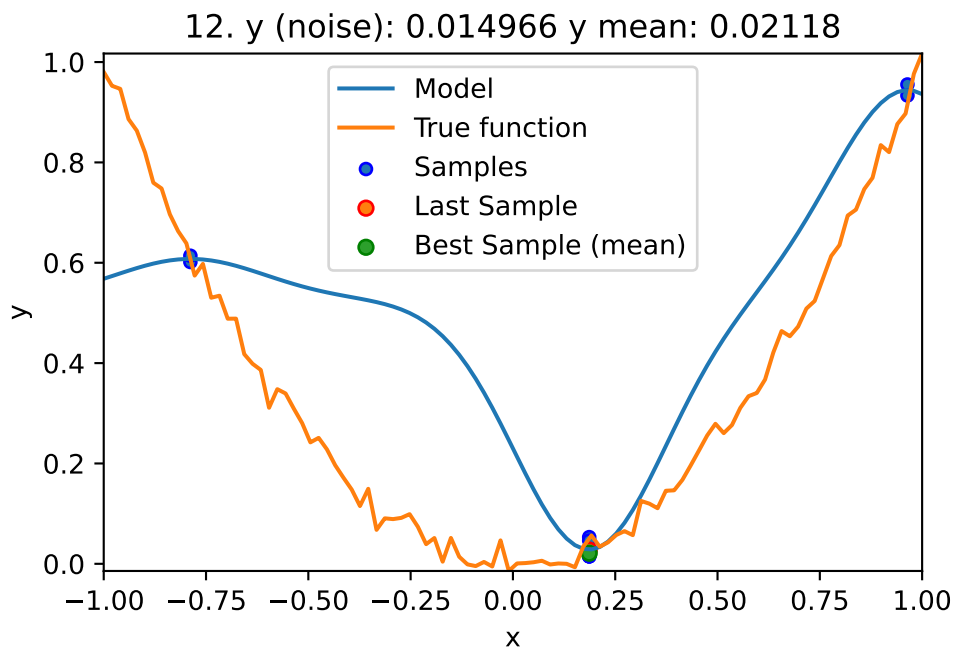
noise = True,
seed=123,
show_models=True,
design_control={"init_size": 3,
               "repeats": 2},
surrogate_control={"noise": True},
fun_control=fun_control,)

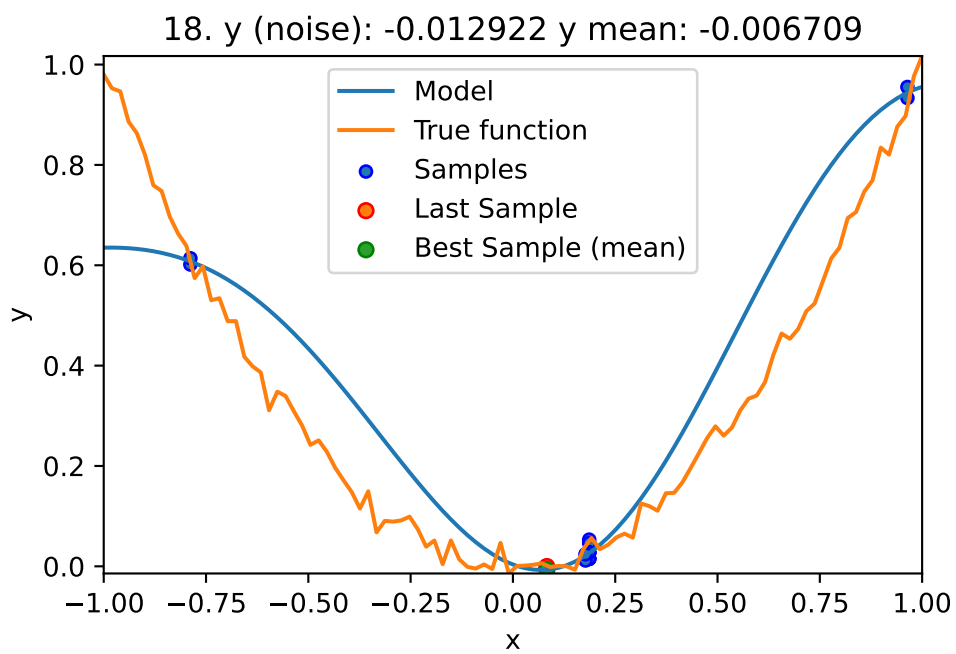
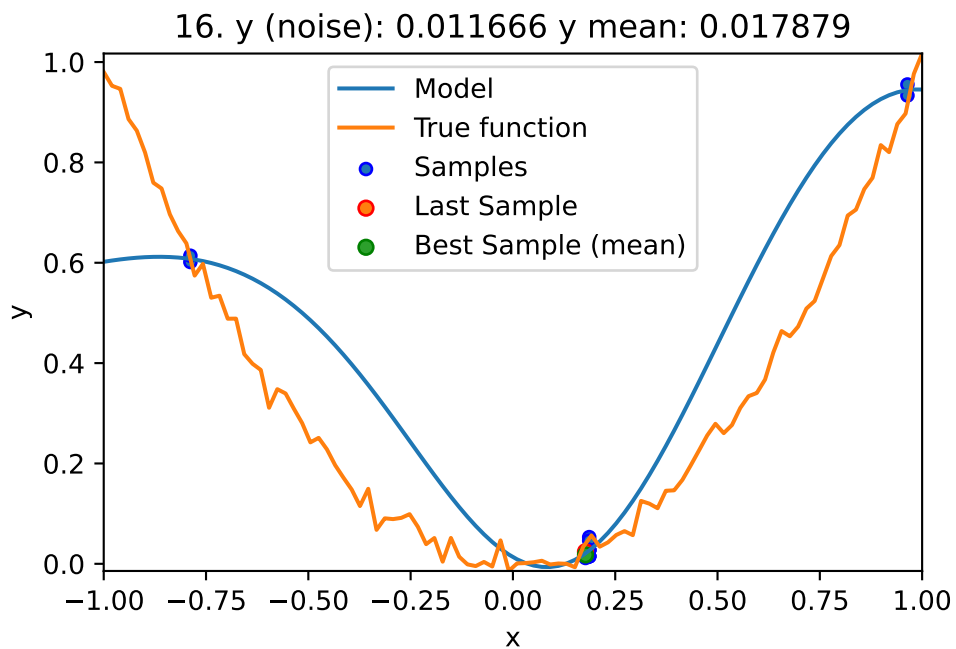
```

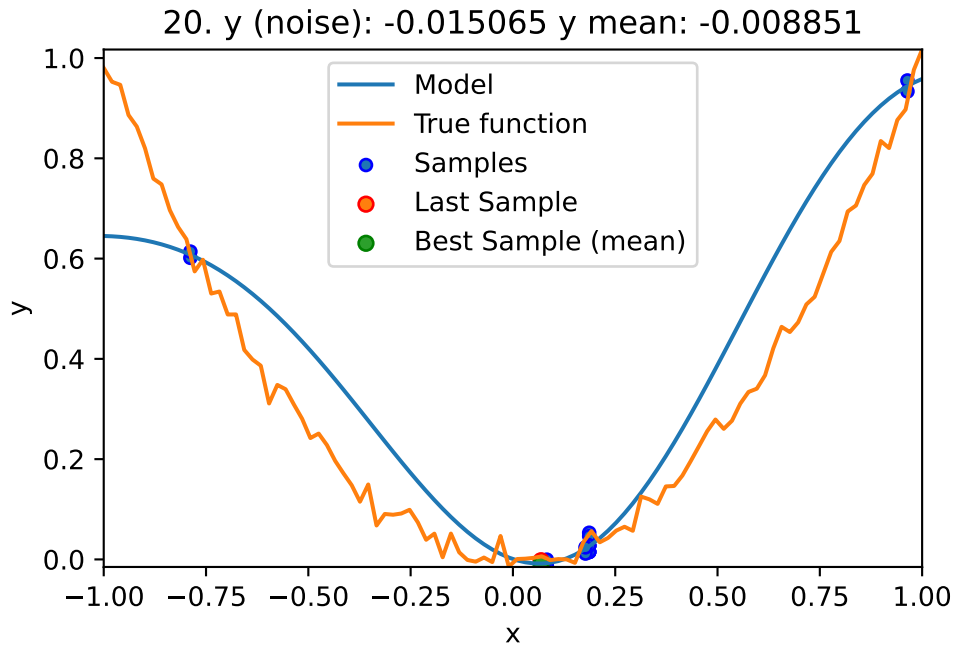
```
spot_1_noisy.run()
```











<spotPython.spot.spot.Spot at 0x2b7d78fa0>

8.2 Print the Results

```
spot_1_noisy.print_results()
```

```
min y: -0.015064679263867698
x0: 0.0686858627600274
min mean y: -0.008851332275068022
x0: 0.0686858627600274
```

```
[['x0', 0.0686858627600274], ['x0', 0.0686858627600274]]
```

```
spot_1_noisy.plot_progress(log_y=False,
                             filename="./figures/" + experiment_name+"_progress.png")
```

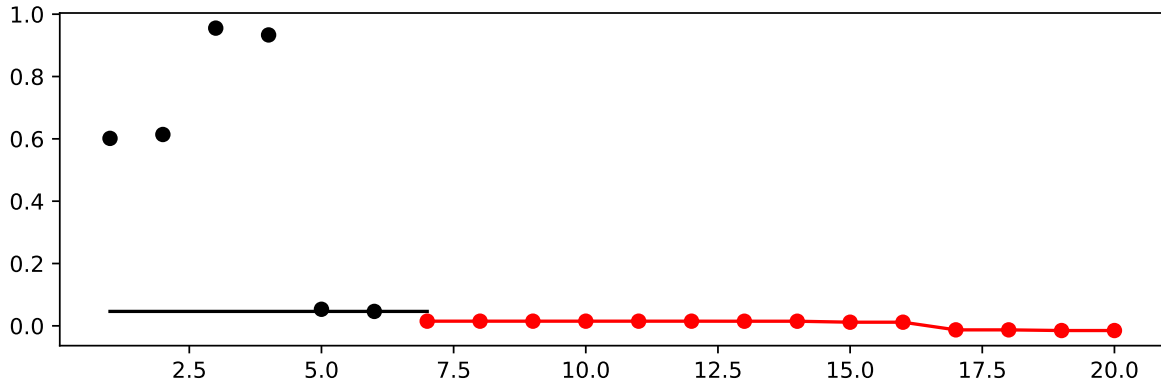


Figure 8.1: Progress plot. *Black* dots denote results from the initial design. *Red* dots illustrate the improvement found by the surrogate model based optimization.

8.3 Noise and Surrogates: The Nugget Effect

8.3.1 The Noisy Sphere

8.3.1.1 The Data

- We prepare some data first:

```
import numpy as np
import spotPython
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
from spotPython.design.spacefilling import spacefilling
from spotPython.build.kriging import Kriging
import matplotlib.pyplot as plt

gen = spacefilling(1)
rng = np.random.RandomState(1)
lower = np.array([-10])
upper = np.array([10])
fun = analytical().fun_sphere
fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    sigma=2,
    seed=123,)
```

```

X = gen.scipy_lhd(10, lower=lower, upper = upper)
y = fun(X, fun_control=fun_control)
X_train = X.reshape(-1,1)
y_train = y

```

- A surrogate without nugget is fitted to these data:

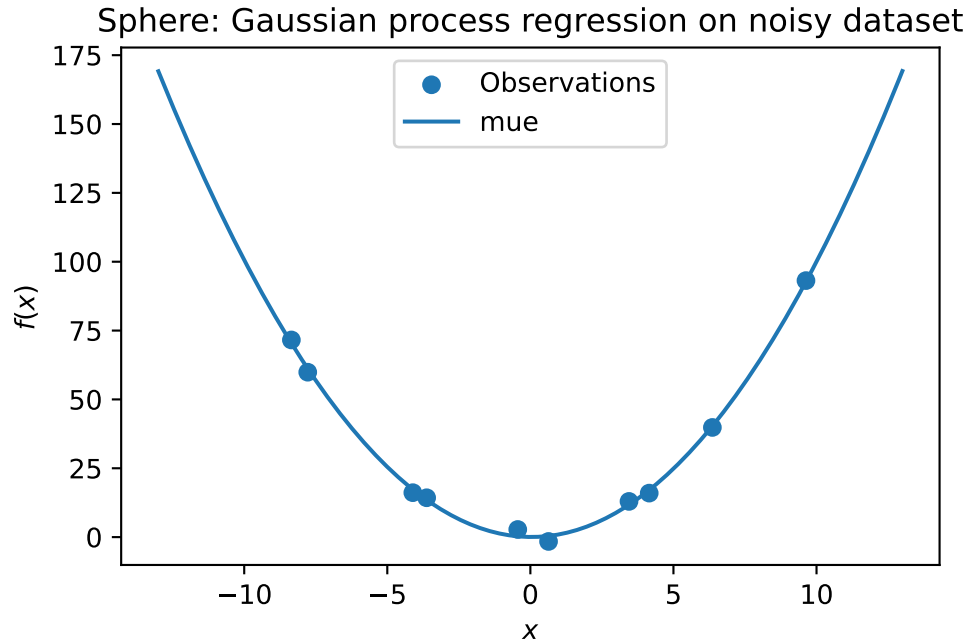
```

S = Kriging(name='kriging',
            seed=123,
            log_level=50,
            n_theta=1,
            noise=False)
S.fit(X_train, y_train)

X_axis = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S.predict(X_axis, return_val="all")

plt.scatter(X_train, y_train, label="Observations")
plt.plot(X_axis, mean_prediction, label="mue")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Sphere: Gaussian process regression on noisy dataset")

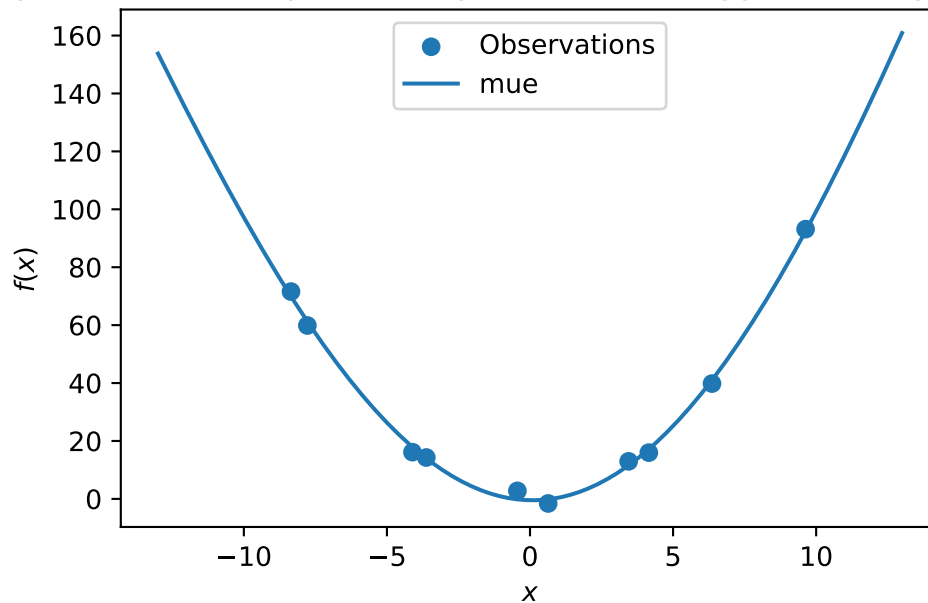
```



- In comparison to the surrogate without nugget, we fit a surrogate with nugget to the data:

```
S_nug = Kriging(name='kriging',
                seed=123,
                log_level=50,
                n_theta=1,
                noise=True)
S_nug.fit(X_train, y_train)
X_axis = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S_nug.predict(X_axis, return_val="all")
plt.scatter(X_train, y_train, label="Observations")
plt.plot(X_axis, mean_prediction, label="mue")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Sphere: Gaussian process regression with nugget on noisy dataset")
```


Sphere: Gaussian process regression with nugget on noisy dataset



- The value of the nugget term can be extracted from the model as follows:

```
S.Lambda
```

```
S_nug.Lambda
```

```
5.208508947162493e-05
```

- We see:
 - the first model `S` has no nugget,
 - whereas the second model has a nugget value (`Lambda`) larger than zero.

8.4 Exercises

8.4.1 Noisy fun_cubed

- Analyse the effect of noise on the `fun_cubed` function with the following settings:

```
fun = analytical().fun_cubed
fun_control = fun_control_init(
```

```

        sigma=10,
        seed=123,)
lower = np.array([-10])
upper = np.array([10])

```

8.4.2 fun_runge

- Analyse the effect of noise on the `fun_runge` function with the following settings:

```

lower = np.array([-10])
upper = np.array([10])
fun = analytical().fun_runge
fun_control = fun_control_init(
    sigma=0.25,
    seed=123,)

```

8.4.3 fun_forrester

- Analyse the effect of noise on the `fun_forrester` function with the following settings:

```

lower = np.array([0])
upper = np.array([1])
fun = analytical().fun_forrester
fun_control = fun_control_init(
    sigma=5,
    seed=123,)

```

8.4.4 fun_xsin

- Analyse the effect of noise on the `fun_xsin` function with the following settings:

```

lower = np.array([-1.])
upper = np.array([1.])
fun = analytical().fun_xsin
fun_control = fun_control_init(
    sigma=0.5,
    seed=123,)

```

9 Handling Noise: Optimal Computational Budget Allocation in Spot

This notebook demonstrates how noisy functions can be handled with OCBA by Spot.

9.1 Example: Spot, OCBA, and the Noisy Sphere Function

```
import numpy as np
from math import inf
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
import matplotlib.pyplot as plt
from spotPython.utils.file import get_experiment_name
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_spot_tensorboard_path

PREFIX = "09"
experiment_name = get_experiment_name(prefix=PREFIX)
print(experiment_name)
```

09_bartz08-2_2023-07-10_00-23-06

9.1.1 The Objective Function: Noisy Sphere

The `spotPython` package provides several classes of objective functions. We will use an analytical objective function with noise, i.e., a function that can be described by a (closed) formula:

$$f(x) = x^2 + \epsilon$$

Since `sigma` is set to 0.1, noise is added to the function:

```

fun = analytical().fun_sphere
fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    sigma=0.1,
    seed=123,)

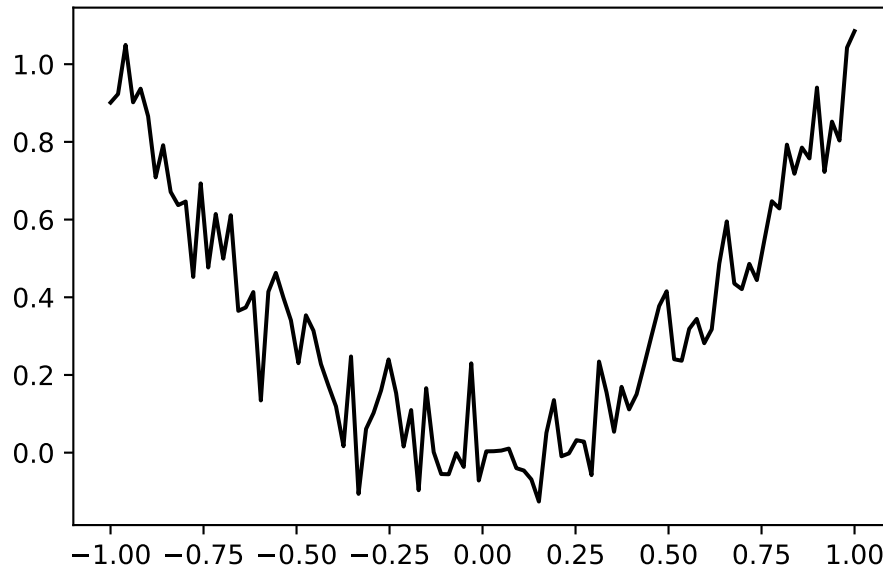
```

A plot illustrates the noise:

```

x = np.linspace(-1,1,100).reshape(-1,1)
y = fun(x, fun_control=fun_control)
plt.figure()
plt.plot(x,y, "k")
plt.show()

```



Spot is adopted as follows to cope with noisy functions:

1. `fun_repeats` is set to a value larger than 1 (here: 2)
2. `noise` is set to `true`. Therefore, a nugget (`Lambda`) term is added to the correlation matrix
3. `init size` (of the `design_control` dictionary) is set to a value larger than 1 (here: 2)

```

spot_1_noisy = spot.Spot(fun=fun,
    lower = np.array([-1]),

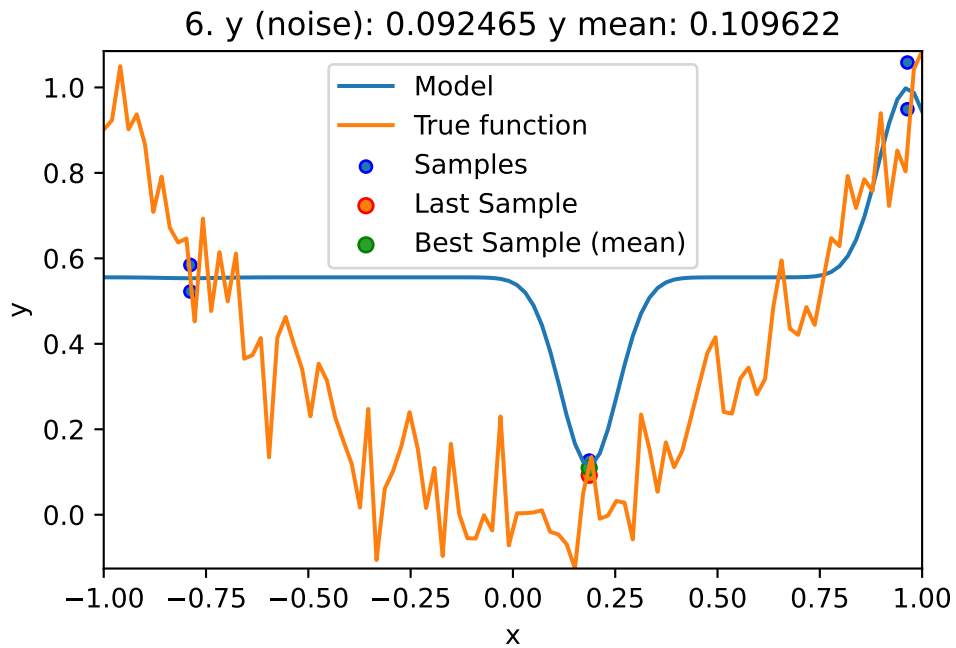
```

```

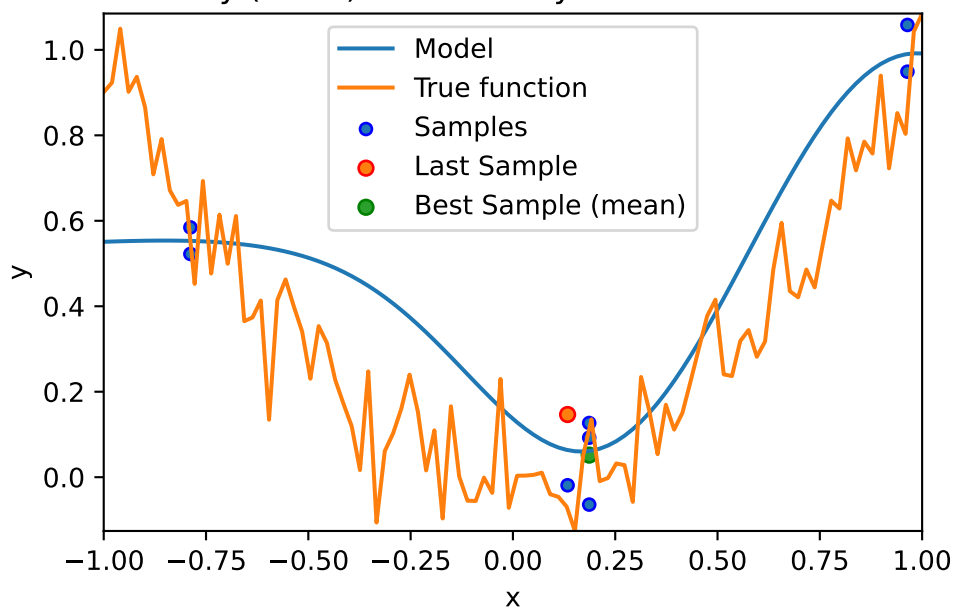
upper = np.array([1]),
fun_evals = 20,
fun_repeats = 2,
infill_criterion="ei",
noise = True,
tolerance_x=0.0,
ocba_delta = 1,
seed=123,
show_models=True,
fun_control = fun_control,
design_control={"init_size": 3,
               "repeats": 2},
surrogate_control={"noise": True})

```

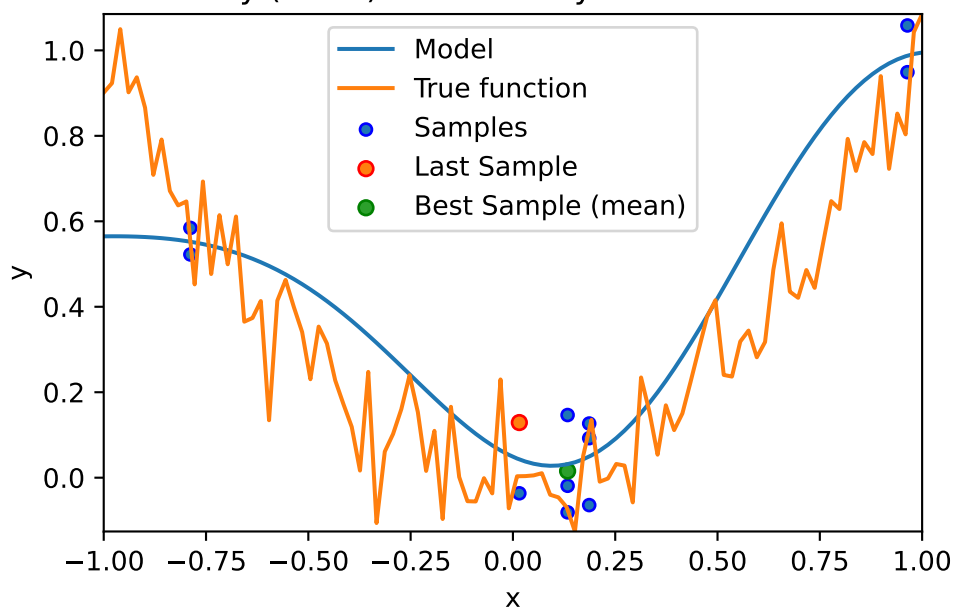
```
spot_1_noisy.run()
```

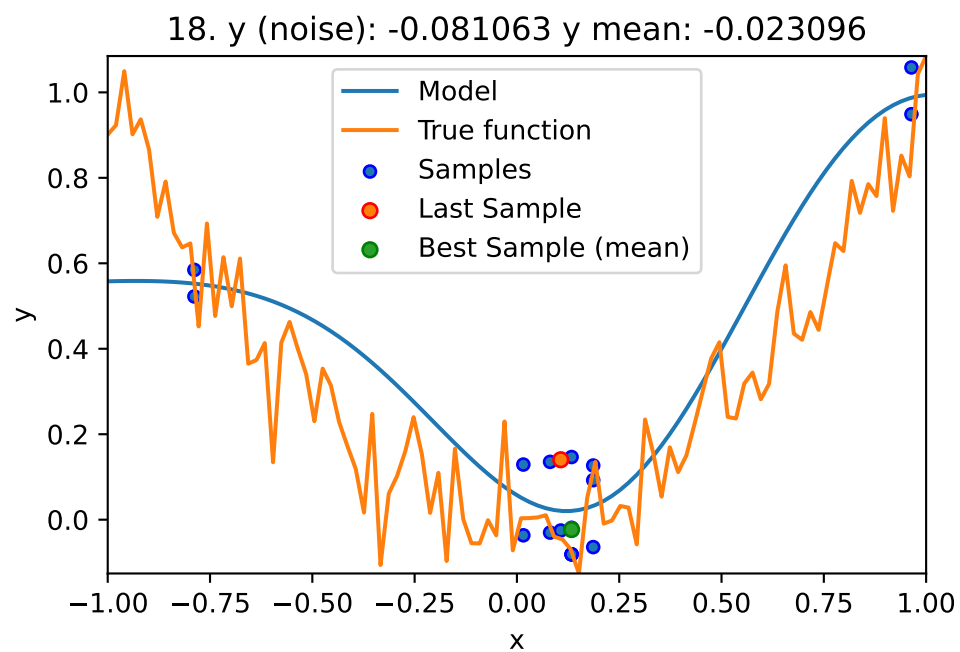
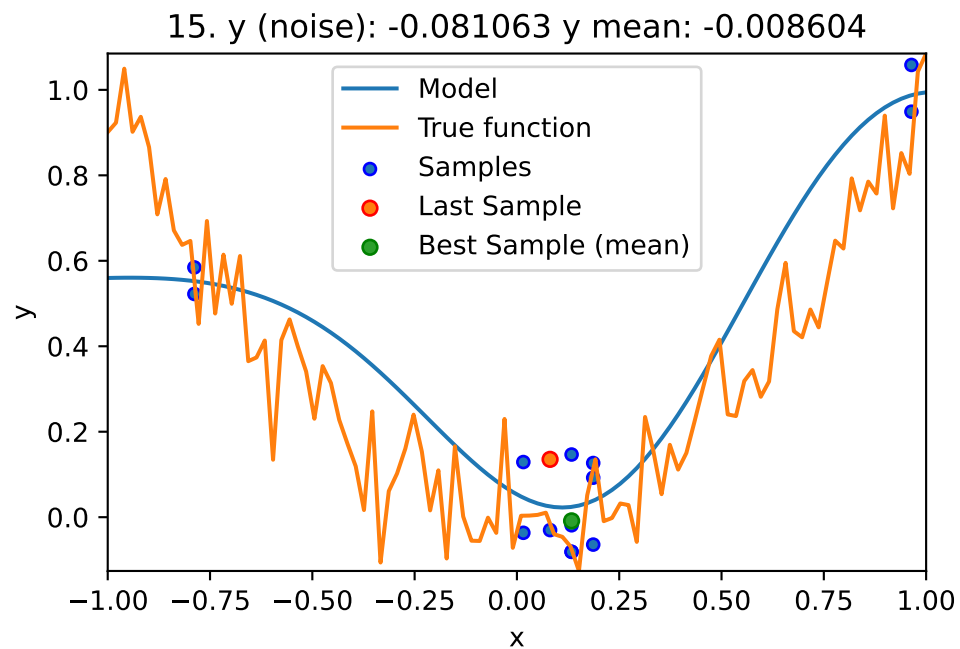


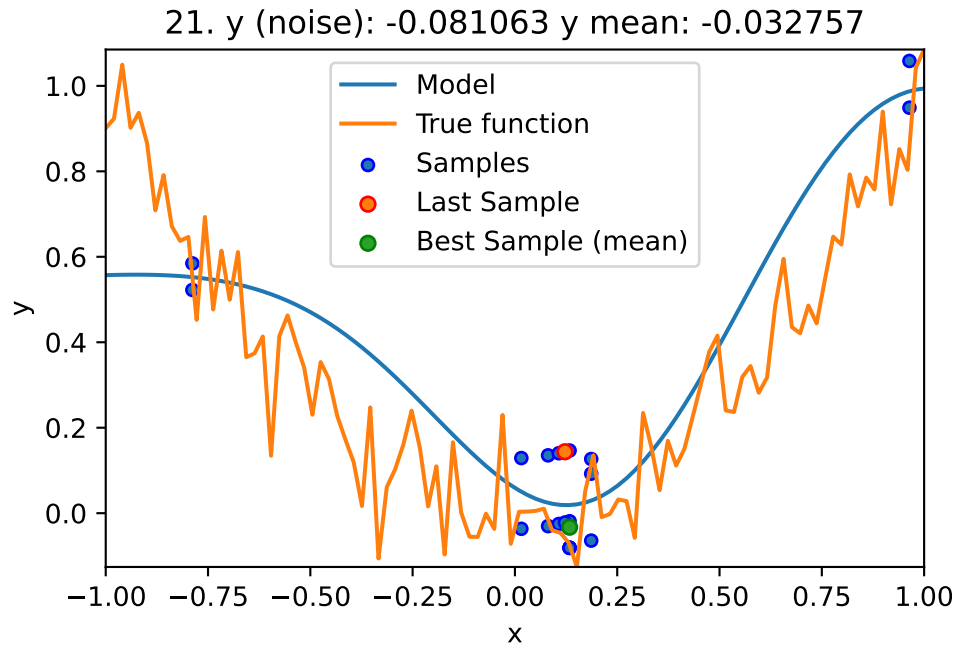
9. y (noise): -0.064157 y mean: 0.051695



12. y (noise): -0.081063 y mean: 0.01555







```
<spotPython.spot.spot.Spot at 0x2b5666770>
```

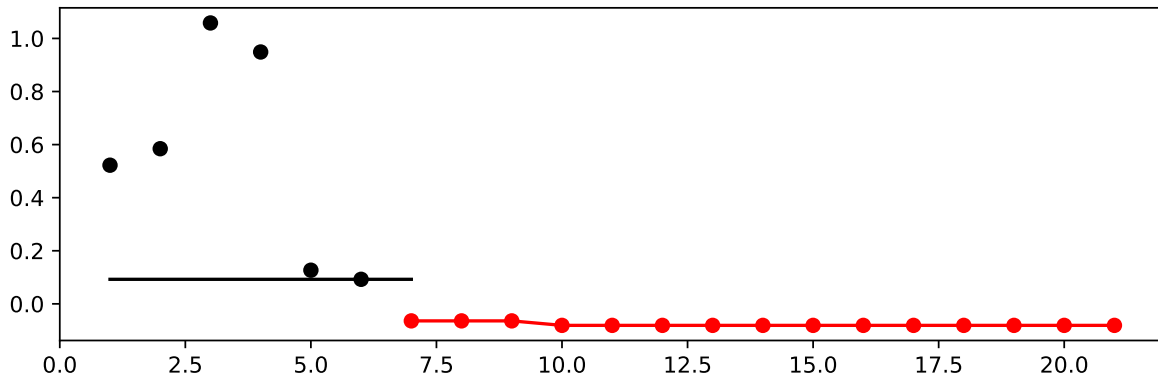
9.2 Print the Results

```
spot_1_noisy.print_results()
```

```
min y: -0.08106318979737473
x0: 0.13359994475077583
min mean y: -0.03275683462209028
x0: 0.13359994475077583
```

```
[['x0', 0.13359994475077583], ['x0', 0.13359994475077583]]
```

```
spot_1_noisy.plot_progress(log_y=False)
```

9.3 Noise and Surrogates: The Nugget Effect

9.3.1 The Noisy Sphere

9.3.1.1 The Data

We prepare some data first:

```
import numpy as np
import spotPython
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
from spotPython.design.spacefilling import spacefilling
from spotPython.build.kriging import Kriging
import matplotlib.pyplot as plt

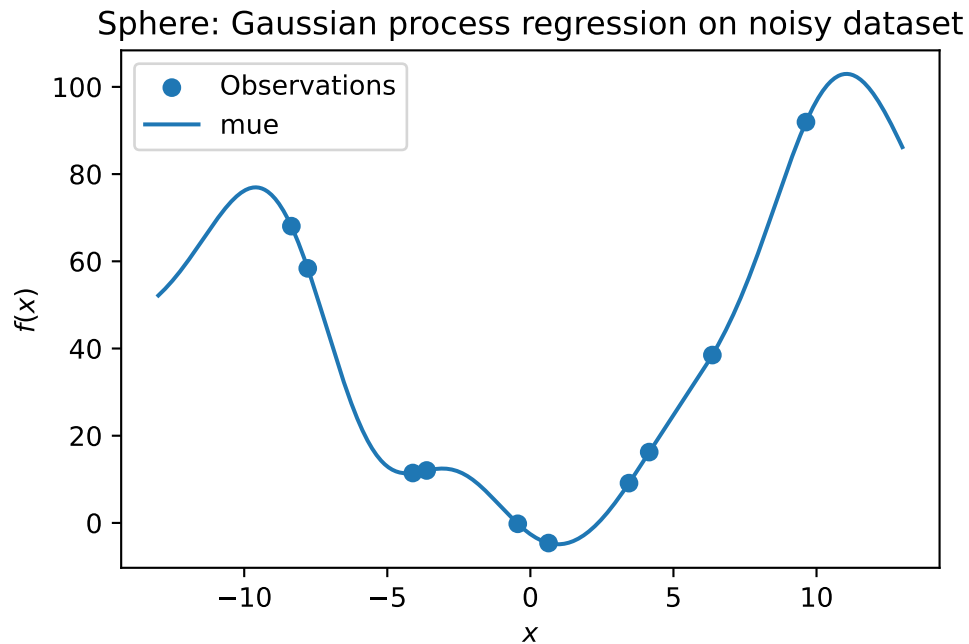
gen = spacefilling(1)
rng = np.random.RandomState(1)
lower = np.array([-10])
upper = np.array([10])
fun = analytical().fun_sphere
fun_control = fun_control_init(
    sigma=2,
    seed=125)
X = gen.scipy_lhd(10, lower=lower, upper = upper)
y = fun(X, fun_control=fun_control)
X_train = X.reshape(-1,1)
y_train = y
```

A surrogate without nugget is fitted to these data:

```
S = Kriging(name='kriging',
            seed=123,
            log_level=50,
            n_theta=1,
            noise=False)
S.fit(X_train, y_train)

X_axis = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S.predict(X_axis, return_val="all")

plt.scatter(X_train, y_train, label="Observations")
plt.plot(X_axis, mean_prediction, label="mue")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Sphere: Gaussian process regression on noisy dataset")
```



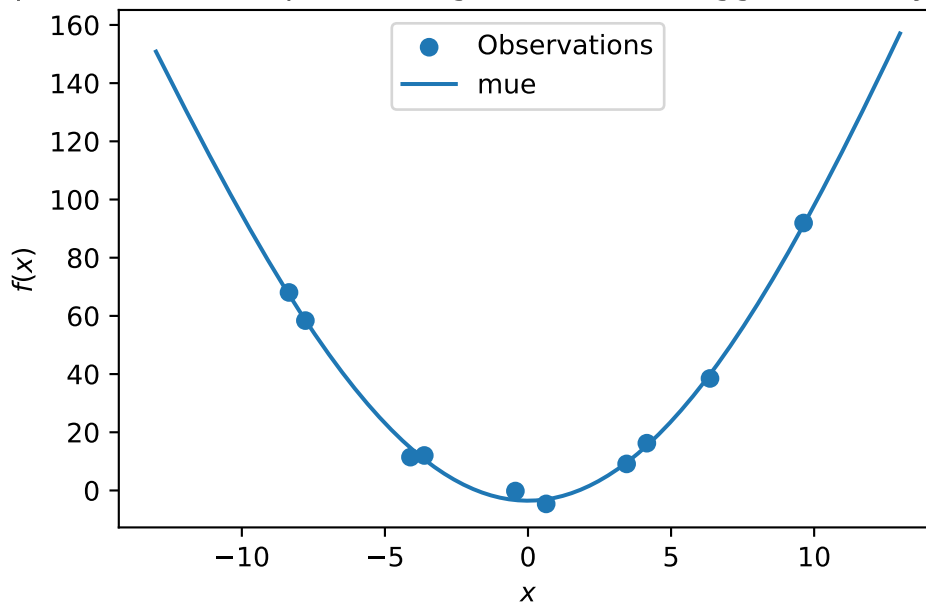
In comparison to the surrogate without nugget, we fit a surrogate with nugget to the data:

```

S_nug = Kriging(name='kriging',
                seed=123,
                log_level=50,
                n_theta=1,
                noise=True)
S_nug.fit(X_train, y_train)
X_axis = np.linspace(start=-13, stop=13, num=1000).reshape(-1, 1)
mean_prediction, std_prediction, ei = S_nug.predict(X_axis, return_val="all")
plt.scatter(X_train, y_train, label="Observations")
plt.plot(X_axis, mean_prediction, label="mue")
plt.legend()
plt.xlabel("$x$")
plt.ylabel("$f(x)$")
_ = plt.title("Sphere: Gaussian process regression with nugget on noisy dataset")

```

Sphere: Gaussian process regression with nugget on noisy dataset



The value of the nugget term can be extracted from the model as follows:

```
S.Lambda
```

```
S_nug.Lambda
```

9.088149959982792e-05

We see:

- the first model **S** has no nugget,
- whereas the second model has a nugget value (**Lambda**) larger than zero.

9.4 Exercises

9.4.1 Noisy fun_cubed

Analyse the effect of noise on the `fun_cubed` function with the following settings:

```
fun = analytical().fun_cubed
fun_control = fun_control_init(
    sigma=10,
    seed=123)
lower = np.array([-10])
upper = np.array([10])
```

9.4.2 fun_runge

Analyse the effect of noise on the `fun_runge` function with the following settings:

```
lower = np.array([-10])
upper = np.array([10])
fun = analytical().fun_runge
fun_control = fun_control_init(
    sigma=0.25,
    seed=123)
```

9.4.3 fun_forrester

Analyse the effect of noise on the `fun_forrester` function with the following settings:

```
lower = np.array([0])
upper = np.array([1])
fun = analytical().fun_forrester
fun_control = {"sigma": 5,
```

```
"seed": 123}
```

9.4.4 fun_xsin

Analyse the effect of noise on the `fun_xsin` function with the following settings:

```
lower = np.array([-1.])
upper = np.array([1.])
fun = analytical().fun_xsin
fun_control = fun_control_init(
    sigma=0.5,
    seed=123)
```


10 HPT: sklearn SVC on Moons Data

spotPython can be installed via pip. Alternatively, the source code can be downloaded from gitHub: <https://github.com/sequential-parameter-optimization/spotPython>.

```
!pip install spotPython
```

10.1 Step 1: Setup

Before we consider the detailed experimental setup, we select the parameters that affect run time, initial design size and the device that is used.

 Caution: Run time and initial design size should be increased for real experiments

- MAX_TIME is set to one minute for demonstration purposes. For real experiments, this should be increased to at least 1 hour.
- INIT_SIZE is set to 5 for demonstration purposes. For real experiments, this should be increased to at least 10.

```
MAX_TIME = 1
INIT_SIZE = 10
PREFIX = "10"
```

10.2 Step 2: Initialization of the Empty fun_control Dictionary

The fun_control dictionary is the central data structure that is used to control the optimization process. It is initialized as follows:

```
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_experiment_name, get_spot_tensorboard_path
from spotPython.utils.device import getDevice

experiment_name = get_experiment_name(prefix=PREFIX)
```

```

fun_control = fun_control_init(
    task="classification",
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    TENSORBOARD_CLEAN=True)

```

10.3 Step 3: SKlearn Load Data (Classification)

Randomly generate classification data.

```

import pandas as pd
import numpy as np
from sklearn.model_selection import train_test_split
from sklearn.datasets import make_moons, make_circles, make_classification
n_features = 2
n_samples = 500
target_column = "y"
ds = make_moons(n_samples, noise=0.5, random_state=0)
X, y = ds
X_train, X_test, y_train, y_test = train_test_split(
    X, y, test_size=0.3, random_state=42
)
train = pd.DataFrame(np.hstack((X_train, y_train.reshape(-1, 1))))
test = pd.DataFrame(np.hstack((X_test, y_test.reshape(-1, 1))))
train.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
test.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
train.head()

```

	x1	x2	y
0	1.960101	0.383172	0.0
1	2.354420	-0.536942	1.0
2	1.682186	-0.332108	0.0
3	1.856507	0.687220	1.0
4	1.925524	0.427413	1.0

```

import matplotlib.pyplot as plt
from matplotlib.colors import ListedColormap

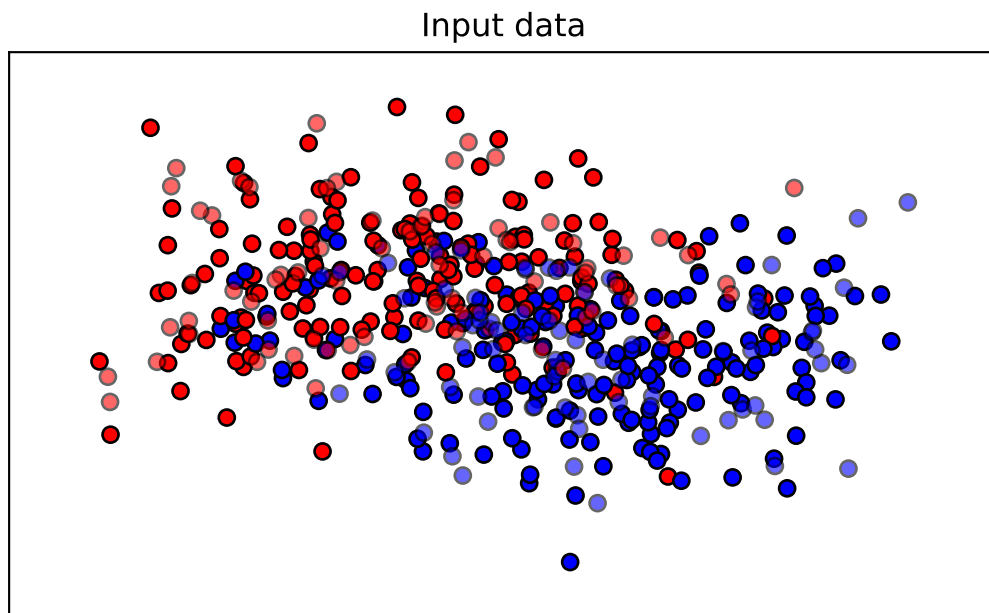
x_min, x_max = X[:, 0].min() - 0.5, X[:, 0].max() + 0.5

```

```

y_min, y_max = X[:, 1].min() - 0.5, X[:, 1].max() + 0.5
cm = plt.cm.RdBu
cm_bright = ListedColormap(["#FF0000", "#0000FF"])
ax = plt.subplot(1, 1, 1)
ax.set_title("Input data")
# Plot the training points
ax.scatter(X_train[:, 0], X_train[:, 1], c=y_train, cmap=cm_bright, edgecolors="k")
# Plot the testing points
ax.scatter(
    X_test[:, 0], X_test[:, 1], c=y_test, cmap=cm_bright, alpha=0.6, edgecolors="k"
)
ax.set_xlim(x_min, x_max)
ax.set_ylim(y_min, y_max)
ax.set_xticks(())
ax.set_yticks(())
plt.tight_layout()
plt.show()

```



```

n_samples = len(train)
# add the dataset to the fun_control
fun_control.update({"data": None, # dataset,

```



```

        "train": train,
        "test": test,
        "n_samples": n_samples,
        "target_column": target_column})

```

10.4 Step 4: Specification of the Preprocessing Model

Data preprocessing can be very simple, e.g., you can ignore it. Then you would choose the `prep_model` "None":

```

prep_model = None
fun_control.update({"prep_model": prep_model})

```

A default approach for numerical data is the `StandardScaler` (mean 0, variance 1). This can be selected as follows:

```

from sklearn.preprocessing import StandardScaler
prep_model = StandardScaler()
fun_control.update({"prep_model": prep_model})

```

Even more complicated pre-processing steps are possible, e.g., the following pipeline:

```

categorical_columns = []
one_hot_encoder = OneHotEncoder(handle_unknown="ignore", sparse_output=False)
prep_model = ColumnTransformer(
    transformers=[
        ("categorical", one_hot_encoder, categorical_columns),
    ],
    remainder=StandardScaler(),
)

```

10.5 Step 5: Select Model (algorithm) and `core_model_hyper_dict`

The selection of the algorithm (ML model) that should be tuned is done by specifying the its name from the `sklearn` implementation. For example, the `SVC` support vector machine classifier is selected as follows:

```

from spotPython.hyperparameters.values import add_core_model_to_fun_control
from spotPython.data.sklearn_hyper_dict import SklearnHyperDict
from sklearn.svm import SVC
add_core_model_to_fun_control(core_model=SVC,
                             fun_control=fun_control,
                             hyper_dict=SklearnHyperDict,
                             filename=None)

```

Now `fun_control` has the information from the JSON file. The corresponding entries for the `core_model` class are shown below.

```
fun_control['core_model_hyper_dict']
```

```

{'C': {'type': 'float',
      'default': 1.0,
      'transform': 'None',
      'lower': 0.1,
      'upper': 10.0},
 'kernel': {'levels': ['linear', 'poly', 'rbf', 'sigmoid'],
            'type': 'factor',
            'default': 'rbf',
            'transform': 'None',
            'core_model_parameter_type': 'str',
            'lower': 0,
            'upper': 3},
 'degree': {'type': 'int',
            'default': 3,
            'transform': 'None',
            'lower': 3,
            'upper': 3},
 'gamma': {'levels': ['scale', 'auto'],
          'type': 'factor',
          'default': 'scale',
          'transform': 'None',
          'core_model_parameter_type': 'str',
          'lower': 0,
          'upper': 1},
 'coef0': {'type': 'float',
          'default': 0.0,
          'transform': 'None',
          'lower': 0.0,
          'upper': 0.0},

```

```

'shrinking': {'levels': [0, 1],
'type': 'factor',
'default': 0,
'transform': 'None',
'core_model_parameter_type': 'bool',
'lower': 0,
'upper': 1},
'probability': {'levels': [0, 1],
'type': 'factor',
'default': 0,
'transform': 'None',
'core_model_parameter_type': 'bool',
'lower': 0,
'upper': 1},
'tol': {'type': 'float',
'default': 0.001,
'transform': 'None',
'lower': 0.0001,
'upper': 0.01},
'cache_size': {'type': 'float',
'default': 200,
'transform': 'None',
'lower': 100,
'upper': 400},
'break_ties': {'levels': [0, 1],
'type': 'factor',
'default': 0,
'transform': 'None',
'core_model_parameter_type': 'bool',
'lower': 0,
'upper': 1}}

```

i sklearn Model Selection

The following **sklearn** models are supported by default:

- RidgeCV
- RandomForestClassifier
- SVC
- LogisticRegression
- KNeighborsClassifier
- GradientBoostingClassifier

- GradientBoostingRegressor
- ElasticNet

They can be imported as follows:

```
from sklearn.linear_model import RidgeCV
from sklearn.ensemble import RandomForestClassifier
from sklearn.svm import SVC
from sklearn.linear_model import LogisticRegression
from sklearn.neighbors import KNeighborsClassifier
from sklearn.ensemble import GradientBoostingClassifier
from sklearn.ensemble import GradientBoostingRegressor
from sklearn.linear_model import ElasticNet
```

10.6 Step 6: Modify hyper_dict Hyperparameters for the Selected Algorithm aka core_model

spotPython provides functions for modifying the hyperparameters, their bounds and factors as well as for activating and de-activating hyperparameters without re-compilation of the Python source code. These functions were described in Section 12.6.

10.6.1 Modify hyperparameter of type numeric and integer (boolean)

Numeric and boolean values can be modified using the `modify_hyper_parameter_bounds` method.

sklearn Model Hyperparameters

The hyperparameters of the `sklearn` SVC model are described in the [sklearn documentation](#).

- For example, to change the `tol` hyperparameter of the SVC model to the interval $[1e-5, 1e-3]$, the following code can be used:

```
from spotPython.hyperparameters.values import modify_hyper_parameter_bounds
modify_hyper_parameter_bounds(fun_control, "tol", bounds=[1e-5, 1e-3])
modify_hyper_parameter_bounds(fun_control, "probability", bounds=[0, 0])
fun_control["core_model_hyper_dict"]["tol"]
```

```
{'type': 'float',
  'default': 0.001,
  'transform': 'None',
  'lower': 1e-05,
  'upper': 0.001}
```

10.6.2 Modify hyperparameter of type factor

Factors can be modified with the `modify_hyper_parameter_levels` function. For example, to exclude the `sigmoid` kernel from the tuning, the `kernel` hyperparameter of the SVC model can be modified as follows:

```
from spotPython.hyperparameters.values import modify_hyper_parameter_levels
modify_hyper_parameter_levels(fun_control, "kernel", ["poly", "rbf"])
fun_control["core_model_hyper_dict"]["kernel"]
```

```
{'levels': ['poly', 'rbf'],
  'type': 'factor',
  'default': 'rbf',
  'transform': 'None',
  'core_model_parameter_type': 'str',
  'lower': 0,
  'upper': 1}
```

10.6.3 Optimizers

Optimizers are described in [Section 12.6.1](#).

10.7 Step 7: Selection of the Objective (Loss) Function

There are two metrics:

1. `metric_river` is used for the river based evaluation via `eval_oml_iter_progressive`.
2. `metric_sklearn` is used for the sklearn based evaluation.

```
from sklearn.metrics import mean_absolute_error, accuracy_score, roc_curve, roc_auc_score,
fun_control.update({
    "metric_sklearn": log_loss,
    "weights": 1.0,
```

```
})
```

metric_sklearn: Minimization and Maximization

- Because the `metric_sklearn` is used for the sklearn based evaluation, it is important to know whether the metric should be minimized or maximized.
- The `weights` parameter is used to indicate whether the metric should be minimized or maximized.
- If `weights` is set to `-1.0`, the metric is maximized.
- If `weights` is set to `1.0`, the metric is minimized, e.g., `weights = 1.0` for `mean_absolute_error`, or `weights = -1.0` for `roc_auc_score`.

10.7.1 Predict Classes or Class Probabilities

If the key `"predict_proba"` is set to `True`, the class probabilities are predicted. `False` is the default, i.e., the classes are predicted.

```
fun_control.update({  
    "predict_proba": False,  
})
```

10.8 Step 8: Calling the SPOT Function

10.8.1 Preparing the SPOT Call

The following code passes the information about the parameter ranges and bounds to `spot`.

```
# extract the variable types, names, and bounds  
from spotPython.hyperparameters.values import (  
    get_var_name,  
    get_var_type,  
    get_bound_values  
)  
var_type = get_var_type(fun_control)  
var_name = get_var_name(fun_control)  
lower = get_bound_values(fun_control, "lower")  
upper = get_bound_values(fun_control, "upper")
```

```
from spotPython.utils.eda import gen_design_table
print(gen_design_table(fun_control))
```

name	type	default	lower	upper	transform
C	float	1.0	0.1	10	None
kernel	factor	rbf	0	1	None
degree	int	3	3	3	None
gamma	factor	scale	0	1	None
coef0	float	0.0	0	0	None
shrinking	factor	0	0	1	None
probability	factor	0	0	0	None
tol	float	0.001	1e-05	0.001	None
cache_size	float	200.0	100	400	None
break_ties	factor	0	0	1	None

10.8.2 The Objective Function

The objective function is selected next. It implements an interface from `sklearn`'s training, validation, and testing methods to `spotPython`.

```
from spotPython.fun.hypersklearn import HyperSklearn
fun = HyperSklearn().fun_sklearn
```

```
from spotPython.hyperparameters.values import get_default_hyperparameters_as_array
# X_start = get_default_hyperparameters_as_array(fun_control)
```

10.8.3 Run the Spot Optimizer

- Run SPOT for approx. x mins (`max_time`).
- Note: the run takes longer, because the evaluation time of initial design (here: `initi_size`, 20 points) is not considered.

10.8.4 Starting the Hyperparameter Tuning

```
import numpy as np
from spotPython.spot import spot
from math import inf
spot_tuner = spot.Spot(fun=fun,
                       lower = lower,
                       upper = upper,
                       fun_evals = inf,
                       fun_repeats = 1,
                       max_time = MAX_TIME,
                       noise = False,
                       tolerance_x = np.sqrt(np.spacing(1)),
                       var_type = var_type,
                       var_name = var_name,
                       infill_criterion = "y",
                       n_points = 1,
                       seed=123,
                       log_level = 50,
                       show_models= False,
                       show_progress= True,
                       fun_control = fun_control,
                       design_control={"init_size": INIT_SIZE,
                                      "repeats": 1},
                       surrogate_control={"noise": True,
                                         "cod_type": "norm",
                                         "min_theta": -4,
                                         "max_theta": 3,
                                         "n_theta": len(var_name),
                                         "model_fun_evals": 10_000,
                                         "log_level": 50
                                         })

spot_tuner.run()
```

spotPython tuning: 5.734217584632275 [-----] 2.36%

spotPython tuning: 5.734217584632275 [#-----] 5.54%

spotPython tuning: 5.734217584632275 [#-----] 9.24%

spotPython tuning: 5.734217584632275 [#-----] 13.07%


```

spotPython tuning: 5.734217584632275 [##-----] 16.46%

spotPython tuning: 5.734217584632275 [##-----] 19.13%

spotPython tuning: 5.734217584632275 [##-----] 21.54%

spotPython tuning: 5.734217584632275 [###-----] 28.69%

spotPython tuning: 5.734217584632275 [####-----] 36.69%

spotPython tuning: 5.734217584632275 [####-----] 43.94%

spotPython tuning: 5.734217584632275 [#####-----] 50.67%

spotPython tuning: 5.734217584632275 [#####-----] 56.67%

spotPython tuning: 5.734217584632275 [#####-----] 63.97%

spotPython tuning: 5.734217584632275 [#####-----] 70.15%

spotPython tuning: 5.734217584632275 [#####-----] 77.37%

spotPython tuning: 5.734217584632275 [#####-----] 85.39%

spotPython tuning: 5.734217584632275 [#####-----] 94.60%

spotPython tuning: 5.734217584632275 [#####] 100.00% Done...

<spotPython.spot.spot.Spot at 0x2bde8f8e0>

```

10.9 Step 9: Results

```

from spotPython.utils.file import save_pickle
save_pickle(spot_tuner, experiment_name)

```

```
from spotPython.utils.file import load_pickle
spot_tuner = load_pickle(experiment_name)
```

- Show the Progress of the hyperparameter tuning:

After the hyperparameter tuning run is finished, the progress of the hyperparameter tuning can be visualized.

```
spot_tuner.plot_progress(log_y=False,
    filename="./figures/" + experiment_name+"_progress.png")
```

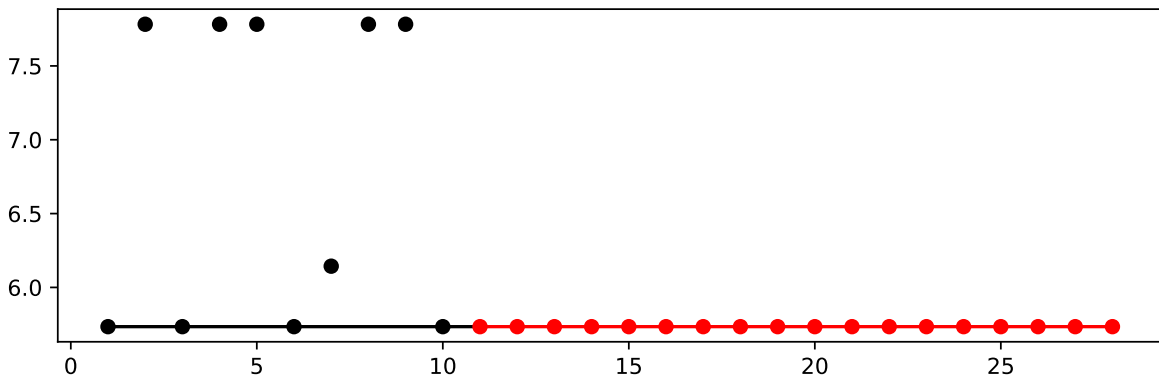


Figure 10.1: Progress plot. *Black* dots denote results from the initial design. *Red* dots illustrate the improvement found by the surrogate model based optimization.

- Print the results

```
print(gen_design_table(fun_control=fun_control,
    spot=spot_tuner))
```

name	type	default	lower	upper	tuned	transform
C	float	1.0	0.1	10.0	2.394471655384338	None
kernel	factor	rbf	0.0	1.0	1.0	None
degree	int	3	3.0	3.0	3.0	None
gamma	factor	scale	0.0	1.0	0.0	None
coef0	float	0.0	0.0	0.0	0.0	None
shrinking	factor	0	0.0	1.0	0.0	None
probability	factor	0	0.0	0.0	0.0	None
tol	float	0.001	1e-05	0.001	0.000982585315792582	None

cache_size	float	200.0		100.0		400.0		375.6371648003268		None
break_ties	factor	0		0.0		1.0		0.0		None

10.9.1 Show variable importance

```
spot_tuner.plot_importance(threshold=0.025, filename="./figures/" + experiment_name+"_impo
```

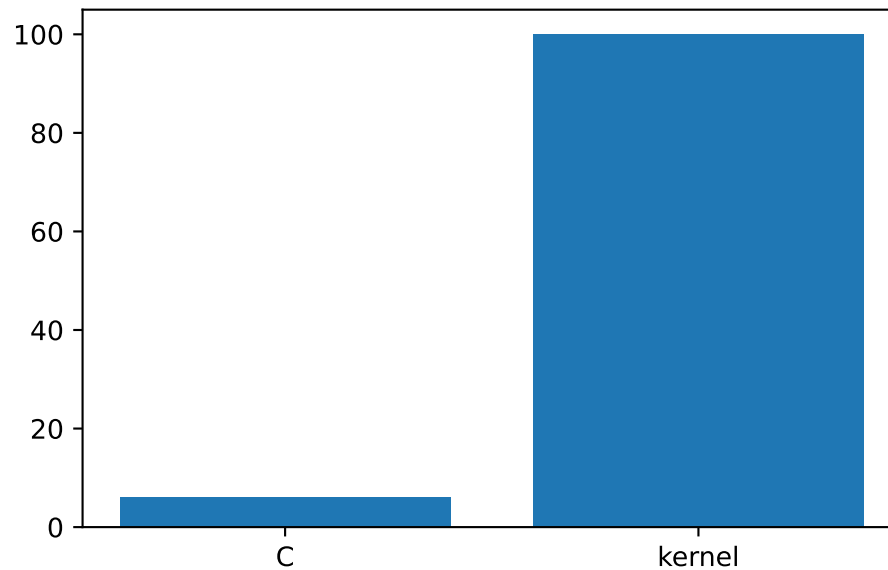


Figure 10.2: Variable importance plot, threshold 0.025.

10.9.2 Get Default Hyperparameters

```
from spotPython.hyperparameters.values import get_default_values, transform_hyper_parameter
values_default = get_default_values(fun_control)
values_default = transform_hyper_parameter_values(fun_control=fun_control, hyper_parameter
values_default
```

```
{'C': 1.0,
 'kernel': 'rbf',
 'degree': 3,
 'gamma': 'scale',
 'coef0': 0.0,
```

```
'shrinking': 0,
'probability': 0,
'tol': 0.001,
'cache_size': 200.0,
'break_ties': 0}
```

```
from sklearn.pipeline import make_pipeline
model_default = make_pipeline(fun_control["prep_model"], fun_control["core_model"](**value
model_default
```

```
Pipeline(steps=[('standardscaler', StandardScaler()),
                 ('svc',
                  SVC(break_ties=0, cache_size=200.0, probability=0,
                      shrinking=0))])
```

10.9.3 Get SPOT Results

```
X = spot_tuner.to_all_dim(spot_tuner.min_X.reshape(1,-1))
print(X)
```

```
[[2.39447166e+00 1.00000000e+00 3.00000000e+00 0.00000000e+00
 0.00000000e+00 0.00000000e+00 0.00000000e+00 9.82585316e-04
 3.75637165e+02 0.00000000e+00]]
```

```
from spotPython.hyperparameters.values import assign_values, return_conf_list_from_var_dict
v_dict = assign_values(X, fun_control["var_name"])
return_conf_list_from_var_dict(var_dict=v_dict, fun_control=fun_control)
```

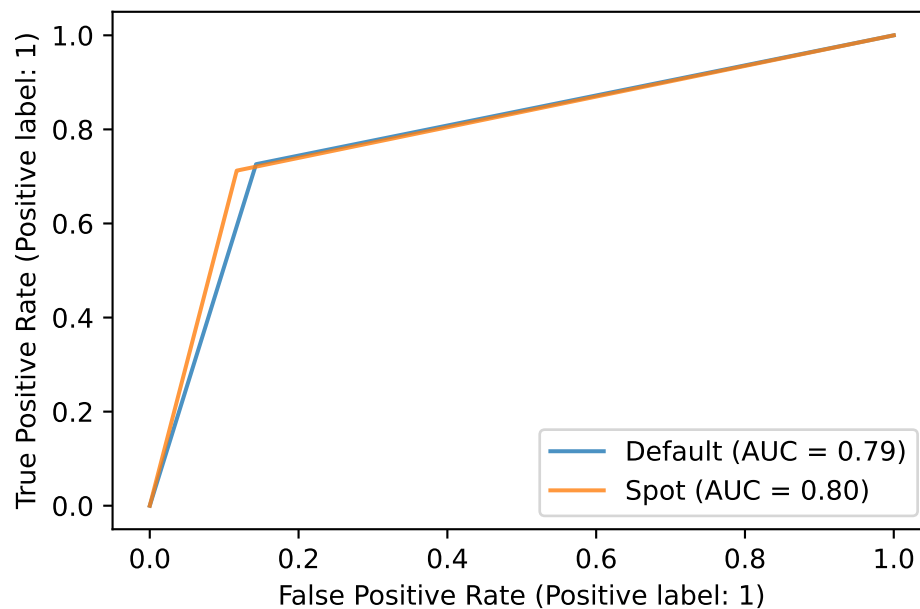
```
[{'C': 2.394471655384338,
 'kernel': 'rbf',
 'degree': 3,
 'gamma': 'scale',
 'coef0': 0.0,
 'shrinking': 0,
 'probability': 0,
 'tol': 0.000982585315792582,
 'cache_size': 375.6371648003268,
 'break_ties': 0}]
```

```
from spotPython.hyperparameters.values import get_one_sklearn_model_from_X
model_spot = get_one_sklearn_model_from_X(X, fun_control)
model_spot
```

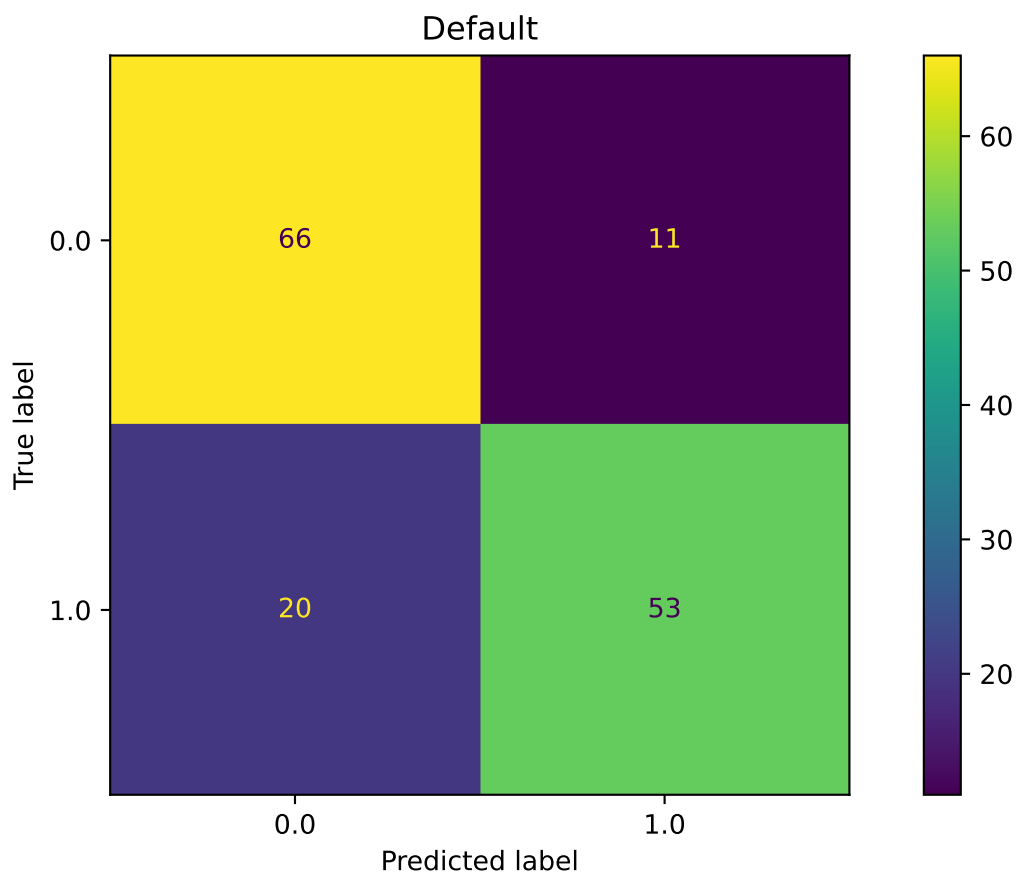
```
Pipeline(steps=[('standardscaler', StandardScaler()),
                 ('svc',
                  SVC(C=2.394471655384338, break_ties=0,
                      cache_size=375.6371648003268, probability=0, shrinking=0,
                      tol=0.000982585315792582))])
```

10.9.4 Plot: Compare Predictions

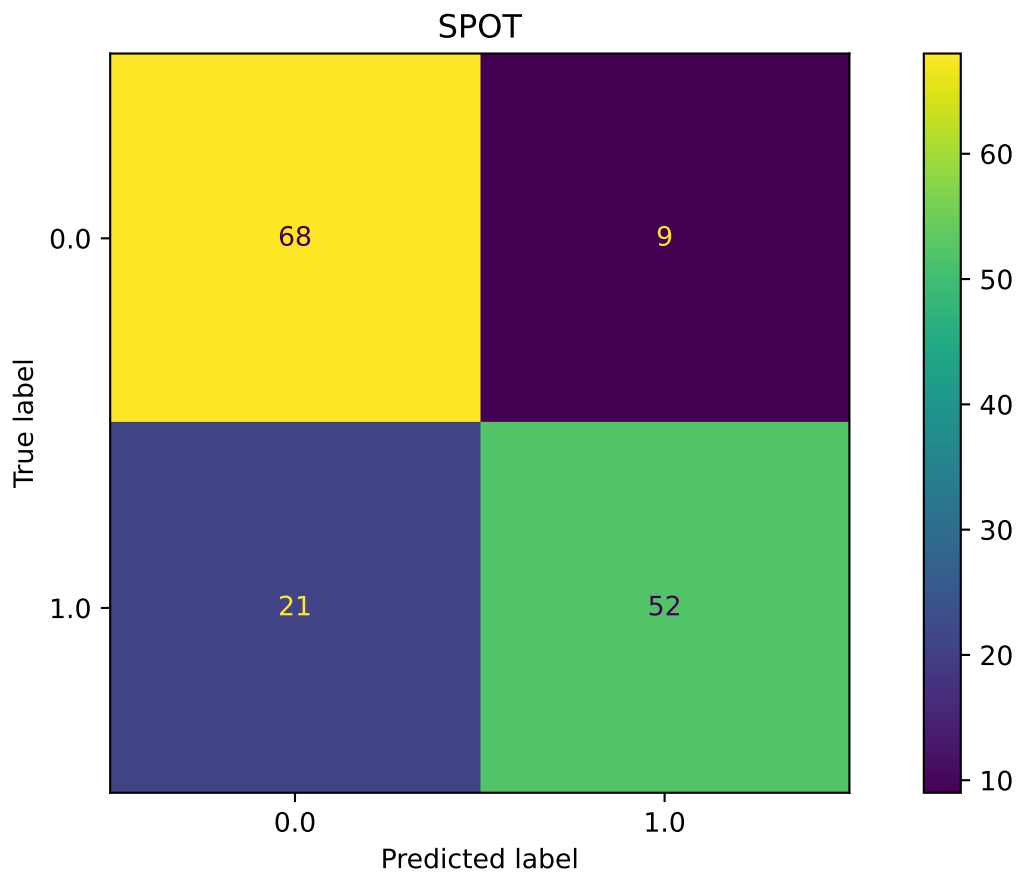
```
from spotPython.plot.validation import plot_roc
plot_roc([model_default, model_spot], fun_control, model_names=["Default", "Spot"])
```



```
from spotPython.plot.validation import plot_confusion_matrix
plot_confusion_matrix(model_default, fun_control, title = "Default")
```



```
plot_confusion_matrix(model_spot, fun_control, title="SPOT")
```



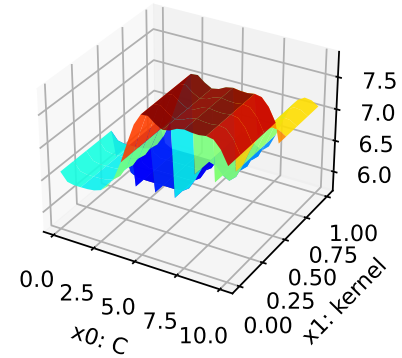
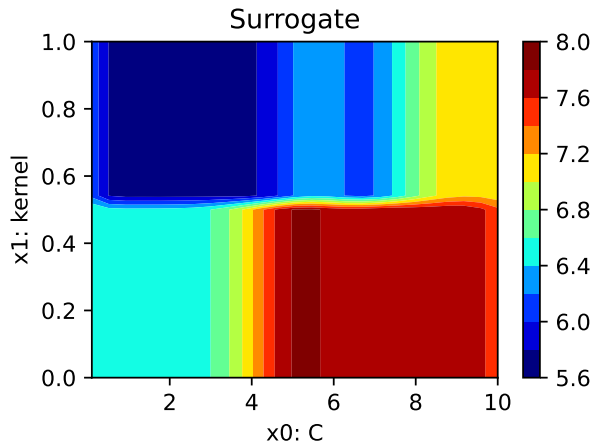
```
min(spot_tuner.y), max(spot_tuner.y)
```

```
(5.734217584632275, 7.782152436286657)
```

10.9.5 Detailed Hyperparameter Plots

```
filename = "./figures/" + experiment_name
spot_tuner.plot_important_hyperparameter_contour(filename=filename)
```

```
C: 5.974249844745921
kernel: 100.0
```



10.9.6 Parallel Coordinates Plot

```
spot_tuner.parallel_plot()
```

Unable to display output for mime type(s): text/html

Unable to display output for mime type(s): text/html

10.9.7 Plot all Combinations of Hyperparameters

- Warning: this may take a while.

```
PLOT_ALL = False
if PLOT_ALL:
    n = spot_tuner.k
    for i in range(n-1):
        for j in range(i+1, n):
            spot_tuner.plot_contour(i=i, j=j, min_z=min_z, max_z = max_z)
```


11 river Hyperparameter Tuning: HATR with Friedman Drift Data

11.1 Setup

Before we consider the detailed experimental setup, we select the parameters that affect run time, initial design size and the device that is used.

 Caution: Run time and initial design size should be increased for real experiments

- MAX_TIME is set to one minute for demonstration purposes. For real experiments, this should be increased to at least 1 hour.
- INIT_SIZE is set to 5 for demonstration purposes. For real experiments, this should be increased to at least 10.
- K is set to 0.1 for demonstration purposes. For real experiments, this should be increased to at least 1.

```
MAX_TIME = 1
INIT_SIZE = 5
PREFIX="10-river"
K = .1
```

10-river_bartz08-2_2023-07-10_00-28-42

- This notebook exemplifies hyperparameter tuning with SPOT (spotPython and spotRiver).
- The hyperparameter software SPOT was developed in R (statistical programming language), see Open Access book “Hyperparameter Tuning for Machine and Deep Learning with R - A Practical Guide”, available here: <https://link.springer.com/book/10.1007/978-981-19-5170-1>.
- This notebook demonstrates hyperparameter tuning for **river**. It is based on the notebook “Incremental decision trees in river: the Hoeffding Tree case”, see: <https://riverml.xyz/0.15.0/recipes/on-hoeffding-trees/#42-regression-tree-splitters>.
- Here we will use the river HTR and HATR functions as in “Incremental decision trees in river: the Hoeffding Tree case”, see: <https://riverml.xyz/0.15.0/recipes/on-hoeffding-trees/#42-regression-tree-splitters>.

11.2 Initialization of the Empty `fun_control` Dictionary

`spotPython` supports the visualization of the hyperparameter tuning process with TensorBoard. The following example shows how to use TensorBoard with `spotPython`.

First, we define an “experiment name” to identify the hyperparameter tuning process. The experiment name is used to create a directory for the TensorBoard files.

```
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_spot_tensorboard_path

experiment_name = get_experiment_name(prefix=PREFIX)
fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    TENSORBOARD_CLEAN=True)
```

Since the `spot_tensorboard_path` is defined, `spotPython` will log the optimization process in the TensorBoard files. The TensorBoard files are stored in the directory `spot_tensorboard_path`. We can pass the TensorBoard information to the `Spot` method via the `fun_control` dictionary.

11.3 Load Data: The Friedman Drift Data

```
horizon = 7*24
k = K
n_total = int(k*100_000)
n_samples = n_total
p_1 = int(k*25_000)
p_2 = int(k*50_000)
position=(p_1, p_2)
n_train = 1_000
a = n_train + p_1 - 12
b = a + 12
```

- Since we also need a `river` version of the data below for plotting the model, the corresponding data set is generated here. Note: `spotRiver` uses the `train` and `test` data sets, while `river` uses the `X` and `y` data sets

```
from river.datasets import synth
import pandas as pd
```

```

dataset = synth.FriedmanDrift(
    drift_type='gra',
    position=position,
    seed=123
)

from spotRiver.utils.data_conversion import convert_to_df
target_column = "y"
df = convert_to_df(dataset, target_column=target_column, n_total=n_total)

# Add column names x1 until x10 to the first 10 columns of the dataframe and the column name y
df.columns = [f"x{i}" for i in range(1, 11)] + ["y"]

train = df[:n_train]
test = df[n_train:]
#
fun_control.update({"data": None, # dataset,
                  "train": train,
                  "test": test,
                  "n_samples": n_samples,
                  "target_column": target_column})

```

11.4 Specification of the Preprocessing Model

```

from river import preprocessing
prep_model = preprocessing.StandardScaler()
fun_control.update({"prep_model": prep_model})

```

11.5 SelectSelect Model (algorithm) and core_model_hyper_dict

- The `river` model (HATR) is selected.
- Furthermore, the corresponding hyperparameters, see: <https://riverml.xyz/0.15.0/api/tree/HoeffdingTreeRegressor/> are selected (incl. type information, names, and bounds).
- The corresponding hyperparameter dictionary is added to the `fun_control` dictionary.
- Alternatively, you can load a local `hyper_dict`. Simply set `river_hyper_dict.json` as the filename. If `filename` is set to `None`, the `hyper_dict` is loaded from the `spotRiver` package.

```

from river.tree import HoeffdingAdaptiveTreeRegressor
from spotRiver.data.river_hyper_dict import RiverHyperDict
from spotPython.hyperparameters.values import add_core_model_to_fun_control
core_model = HoeffdingAdaptiveTreeRegressor
add_core_model_to_fun_control(core_model=core_model,
                             fun_control=fun_control,
                             hyper_dict=RiverHyperDict,
                             filename=None)

```

11.6 Modify hyper_dict Hyperparameters for the Selected Algorithm aka core_model

11.6.1 Modify hyperparameter of type factor

```

# modify_hyper_parameter_levels(fun_control, "leaf_model", ["LinearRegression"])
# fun_control["core_model_hyper_dict"]

```

11.6.2 Modify hyperparameter of type numeric and integer (boolean)

```

from spotPython.hyperparameters.values import modify_hyper_parameter_bounds
modify_hyper_parameter_bounds(fun_control, "delta", bounds=[1e-10, 1e-6])
# modify_hyper_parameter_bounds(fun_control, "min_samples_split", bounds=[3, 20])
modify_hyper_parameter_bounds(fun_control, "merit_preprune", [0, 0])

```

11.7 Selection of the Objective (Loss) Function

There are two metrics:

1. ``metric`` is used for the river based evaluation via ``eval_oml_iter_progressive``.
2. ``metric_sklearn`` is used for the sklearn based evaluation via ``eval_oml_horizon``.

```

import numpy as np
from river import metrics
from sklearn.metrics import mean_absolute_error

```

```

weights = np.array([1, 1/1000, 1/1000])*10_000.0
horizon = 7*24
oml_grace_period = 2
step = 100
weight_coeff = 1.0

fun_control.update({
    "horizon": horizon,
    "oml_grace_period": oml_grace_period,
    "weights": weights,
    "step": step,
    "log_level": 50,
    "weight_coeff": weight_coeff,
    "metric": metrics.MAE(),
    "metric_sklearn": mean_absolute_error
})

```

11.8 Calling the SPOT Function

11.8.1 Prepare the SPOT Parameters

- Get types and variable names as well as lower and upper bounds for the hyperparameters.

```

from spotPython.hyperparameters.values import (
    get_var_type,
    get_var_name,
    get_bound_values
)
var_type = get_var_type(fun_control)
var_name = get_var_name(fun_control)
lower = get_bound_values(fun_control, "lower")
upper = get_bound_values(fun_control, "upper")

from spotPython.utils.eda import gen_design_table
print(gen_design_table(fun_control))

```

name	type	default	lower	upper	transform
grace_period	int	200	10	1000	None

max_depth	int	20		2		20	transform_pow
delta	float	1e-07		1e-10		1e-06	None
tau	float	0.05		0.01		0.1	None
leaf_prediction	factor	mean		0		2	None
leaf_model	factor	LinearRegression		0		2	None
model_selector_decay	float	0.95		0.9		0.99	None
splitter	factor	EBSTSplitter		0		2	None
min_samples_split	int	5		2		10	None
bootstrap_sampling	factor	0		0		1	None
drift_window_threshold	int	300		100		500	None
switch_significance	float	0.05		0.01		0.1	None
binary_split	factor	0		0		1	None
max_size	float	500.0		100		1000	None
memory_estimate_period	int	1000000		100000		1e+06	None
stop_mem_management	factor	0		0		1	None
remove_poor_attrs	factor	0		0		1	None
merit_preprune	factor	0		0		0	None

11.8.2 The Objective Function

The objective function is selected next.

```
from spotRiver.fun.hyperriver import HyperRiver
fun = HyperRiver().fun_oml_horizon
```

```
from spotPython.hyperparameters.values import get_default_hyperparameters_as_array
X_start = get_default_hyperparameters_as_array(fun_control)
```

11.8.3 Run the Spot Optimizer

- Run SPOT for approx. x mins (max_time).
- Note: the run takes longer, because the evaluation time of initial design (here: init_size = INIT_SIZE as specified above) is not considered.

```
from spotPython.spot import spot
from math import inf
import numpy as np
spot_tuner = spot.Spot(fun=fun,
                      lower = lower,
                      upper = upper,
```

```

        fun_evals = inf,
        infill_criterion = "y",
        max_time = MAX_TIME,
        tolerance_x = np.sqrt(np.spacing(1)),
        var_type = var_type,
        var_name = var_name,
        show_progress= True,
        fun_control = fun_control,
        design_control={"init_size": INIT_SIZE},
        surrogate_control={"noise": False,
                           "cod_type": "norm",
                           "min_theta": -4,
                           "max_theta": 3,
                           "n_theta": len(var_name),
                           "model_fun_evals": 10_000})

spot_tuner.run(X_start=X_start)

```

spotPython tuning: 2.2089244963523553 [#-----] 13.42%

spotPython tuning: 2.2089244963523553 [###-----] 28.59%

Error in fun_oml_horizon(). Call to eval_oml_horizon failed. err=ZeroDivisionError('float di
Error in fun(). Call to evaluate or compute_y failed. err=UnboundLocalError("local variable
Setting y to np.nan.

spotPython tuning: 2.2089244963523553 [####-----] 39.25%

Error in fun_oml_horizon(). Call to eval_oml_horizon failed. err=ZeroDivisionError('float di
Error in fun(). Call to evaluate or compute_y failed. err=UnboundLocalError("local variable
Setting y to np.nan.

spotPython tuning: 2.2089244963523553 [#####-----] 51.36%

Error in fun_oml_horizon(). Call to eval_oml_horizon failed. err=ZeroDivisionError('float di
Error in fun(). Call to evaluate or compute_y failed. err=UnboundLocalError("local variable
Setting y to np.nan.

spotPython tuning: 2.2089244963523553 [#####-----] 62.10%

```
Error in fun_oml_horizon(). Call to eval_oml_horizon failed. err=ZeroDivisionError('float di
Error in fun(). Call to evaluate or compute_y failed. err=UnboundLocalError("local variable
Setting y to np.nan.
```

```
spotPython tuning: 2.2089244963523553 [#####---] 72.84%
```

```
Error in fun_oml_horizon(). Call to eval_oml_horizon failed. err=ZeroDivisionError('float di
Error in fun(). Call to evaluate or compute_y failed. err=UnboundLocalError("local variable
Setting y to np.nan.
```

```
spotPython tuning: 2.2089244963523553 [#####--] 83.53%
```

```
Error in fun_oml_horizon(). Call to eval_oml_horizon failed. err=ZeroDivisionError('float di
Error in fun(). Call to evaluate or compute_y failed. err=UnboundLocalError("local variable
Setting y to np.nan.
```

```
spotPython tuning: 2.2089244963523553 [#####-] 94.19%
```

```
spotPython tuning: 2.2089244963523553 [#####] 100.00% Done...
```

```
<spotPython.spot.spot.Spot at 0x2c9d7ab00>
```

11.8.4 TensorBoard

Now we can start TensorBoard in the background with the following command:

```
tensorboard --logdir="./runs"
```

We can access the TensorBoard web server with the following URL:

```
http://localhost:6006/
```

The TensorBoard plot illustrates how `spotPython` can be used as a microscope for the internal mechanisms of the surrogate-based optimization process. Here, one important parameter, the learning rate θ of the Kriging surrogate is plotted against the number of optimization steps.

11.8.5 Results

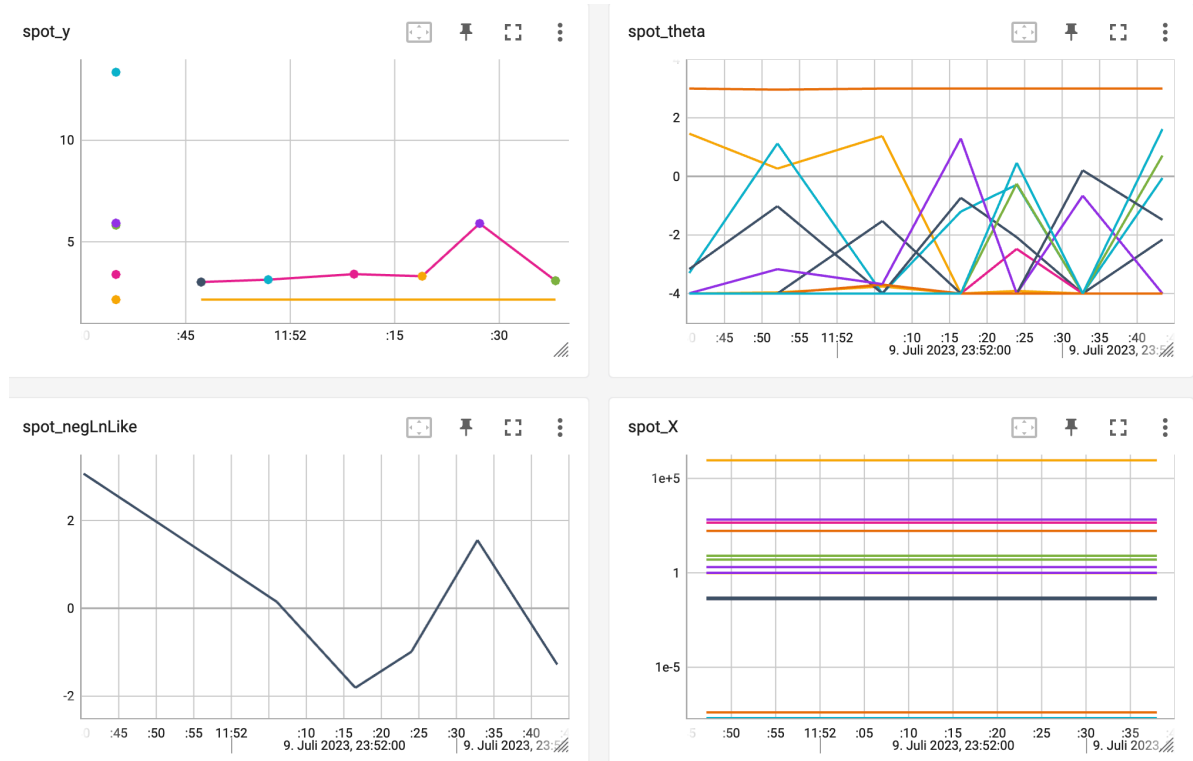


Figure 11.1: TensorBoard visualization of the spotPython optimization process and the surrogate model.

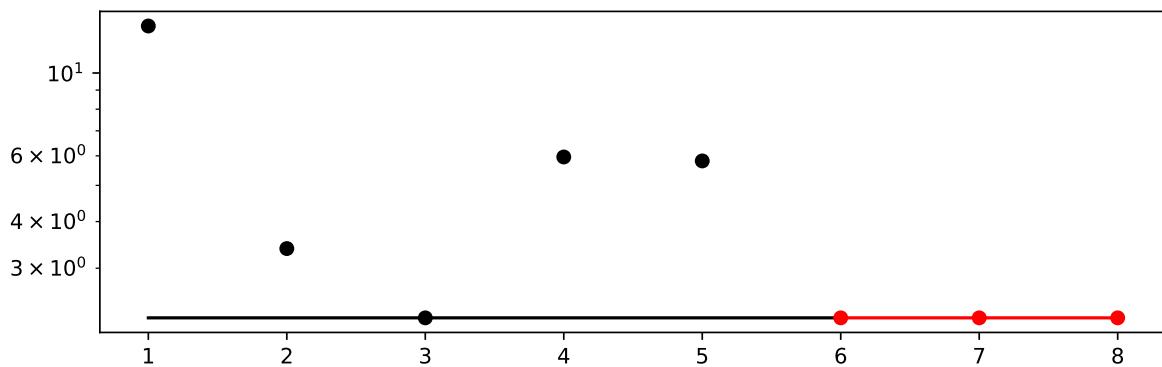
```
from spotPython.utils.file import save_pickle
save_pickle(spot_tuner, experiment_name)
```

```
from spotPython.utils.file import load_pickle
spot_tuner = load_pickle(experiment_name)
```

- Show the Progress of the hyperparameter tuning:

After the hyperparameter tuning run is finished, the progress of the hyperparameter tuning can be visualized.

```
spot_tuner.plot_progress(log_y=True, filename="./figures/" + experiment_name+"_progress.pdf")
```



- Print the Results

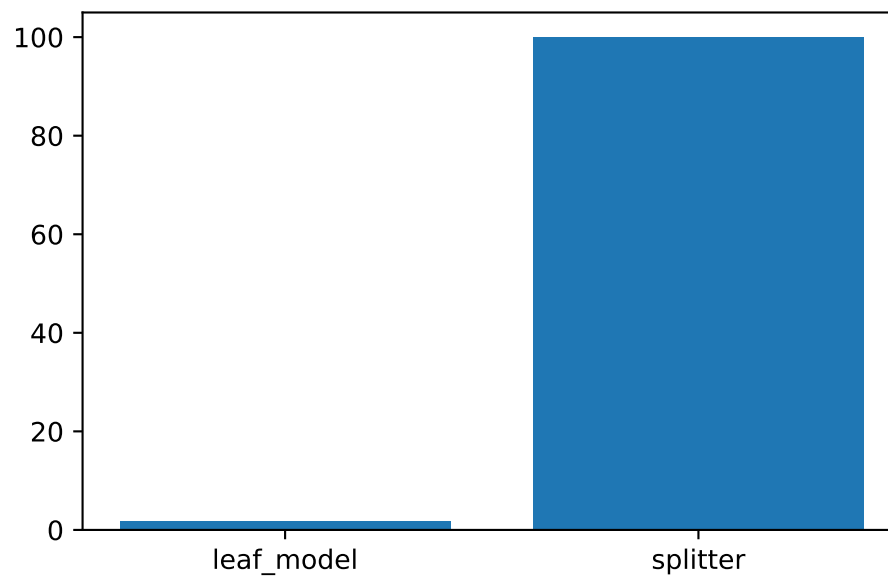
```
print(gen_design_table(fun_control=fun_control, spot=spot_tuner))
```

name	type	default	lower	upper	
grace_period	int	200	10.0	1000.0	
max_depth	int	20	2.0	20.0	
delta	float	1e-07	1e-10	1e-06	4.068723023437
tau	float	0.05	0.01	0.1	0.0484260091
leaf_prediction	factor	mean	0.0	2.0	
leaf_model	factor	LinearRegression	0.0	2.0	
model_selector_decay	float	0.95	0.9	0.99	0.970713237
splitter	factor	EBSTSplitter	0.0	2.0	
min_samples_split	int	5	2.0	10.0	
bootstrap_sampling	factor	0	0.0	1.0	

drift_window_threshold	int	300		100.0		500.0		
switch_significance	float	0.05		0.01		0.1		0.040370639
binary_split	factor	0		0.0		1.0		
max_size	float	500.0		100.0		1000.0		454.140654
memory_estimate_period	int	1000000		100000.0		1000000.0		9
stop_mem_management	factor	0		0.0		1.0		
remove_poor_attrs	factor	0		0.0		1.0		
merit_preprune	factor	0		0.0		0.0		

11.9 Show variable importance

```
spot_tuner.plot_importance(threshold=0.0025, filename="./figures/" + experiment_name+"_imp
```



11.10 Build and Evaluate HTR Model with Tuned Hyperparameters

```
m = test.shape[0]
a = int(m/2)-50
b = int(m/2)
```

11.11 Der große Datensatz

Caution: Increased Friedman-Drift Data Set

- The Friedman-Drift Data Set is increased by a factor of two to show the transferability of the hyperparameter tuning results.
- Larger values of `k` lead to a longer run time.

```
horizon = 7*24
k = 0.2
n_total = int(k*100_000)
n_samples = n_total
p_1 = int(k*25_000)
p_2 = int(k*50_000)
position=(p_1, p_2)
n_train = 1_000
a = n_train + p_1 - 12
b = a + 12
```

```
from river.datasets import synth
dataset = synth.FriedmanDrift(
    drift_type='gra',
    position=position,
    seed=123
)
```

```
from spotRiver.utils.data_conversion import convert_to_df
target_column = "y"
df = convert_to_df(dataset, target_column=target_column, n_total=n_total)
# Add column names x1 until x10 to the first 10 columns of the dataframe and the column name y
df.columns = [f"x{i}" for i in range(1, 11)] + ["y"]
train = df[:n_train]
test = df[n_train:]
target_column = "y"
#
fun_control.update({"data": None, # dataset,
                  "train": train,
                  "test": test,
                  "n_samples": n_samples,
                  "target_column": target_column})
```

11.12 Get Default Hyperparameters

```
# fun_control was modified, we generate a new one with the original
# default hyperparameters
from spotPython.hyperparameters.values import get_one_core_model_from_X
from spotPython.hyperparameters.values import get_default_hyperparameters_as_array
X_start = get_default_hyperparameters_as_array(fun_control)
model_default = get_one_core_model_from_X(X_start, fun_control)
model_default
```

```
HoeffdingAdaptiveTreeRegressor (
  grace_period=200
  max_depth=1048576
  delta=1e-07
  tau=0.05
  leaf_prediction="mean"
  leaf_model=LinearRegression (
    optimizer=SGD (
      lr=Constant (
        learning_rate=0.01
      )
    )
    loss=Squared ()
    l2=0.
    l1=0.
    intercept_init=0.
    intercept_lr=Constant (
      learning_rate=0.01
    )
    clip_gradient=1e+12
    initializer=Zeros ()
  )
  model_selector_decay=0.95
  nominal_attributes=None
  splitter=EBSTSplitter ()
  min_samples_split=5
  bootstrap_sampling=0
  drift_window_threshold=300
  drift_detector=ADWIN (
    delta=0.002
    clock=32
```

```

        max_buckets=5
        min_window_length=5
        grace_period=10
    )
    switch_significance=0.05
    binary_split=0
    max_size=500.
    memory_estimate_period=1000000
    stop_mem_management=0
    remove_poor_attrs=0
    merit_preprune=0
    seed=None
)

```

```

from spotRiver.evaluation.eval_bml import eval_oml_horizon

```

```

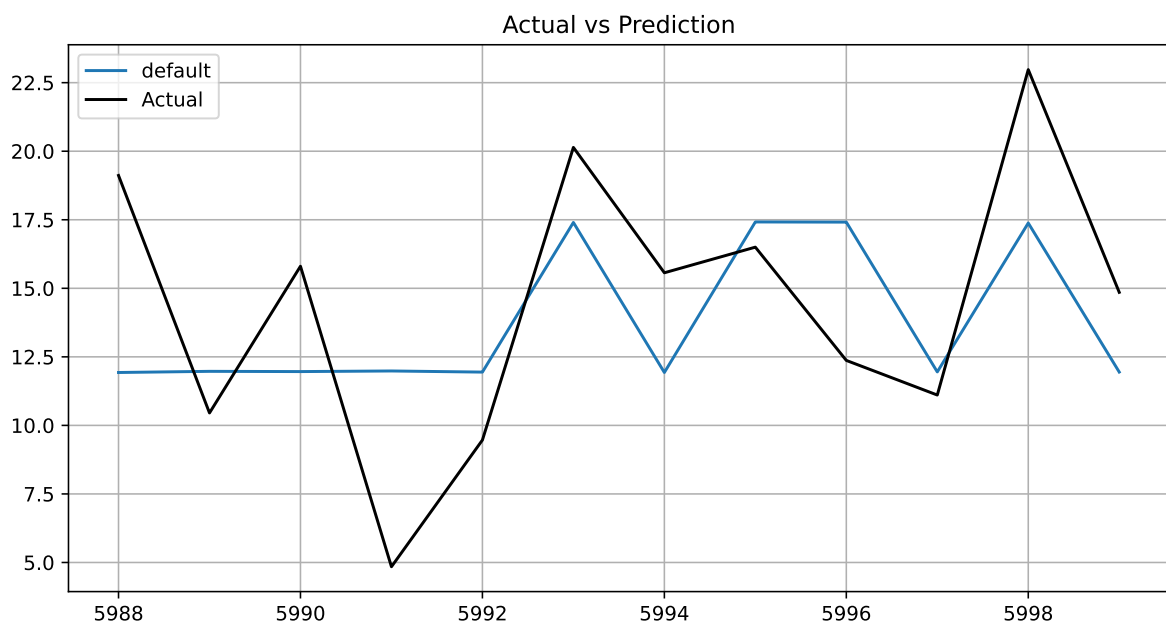
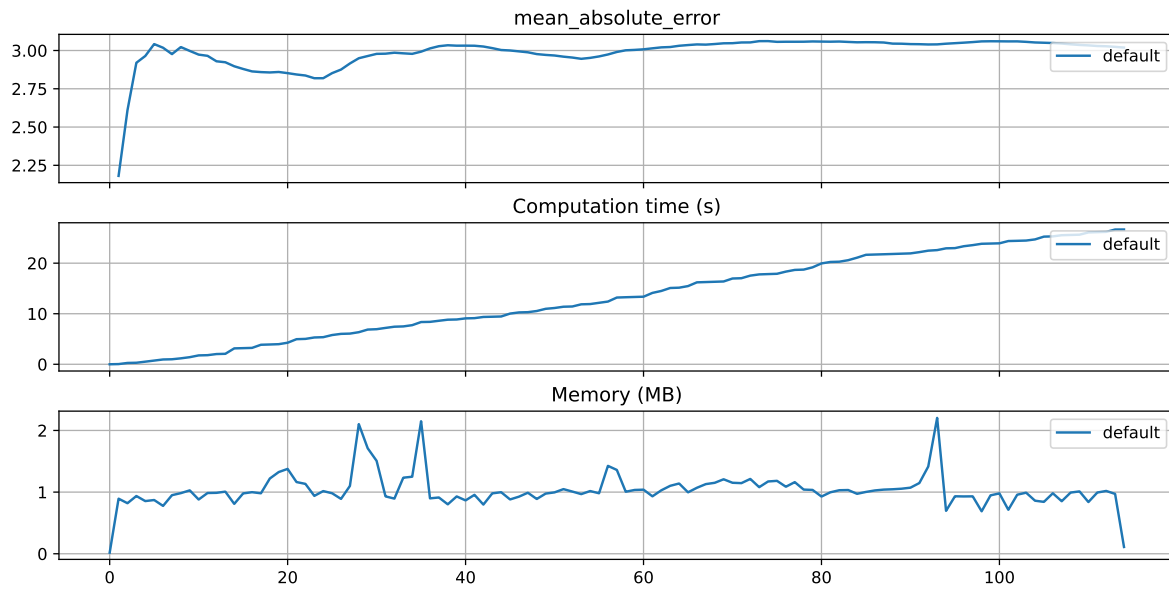
df_eval_default, df_true_default = eval_oml_horizon(
    model=model_default,
    train=fun_control["train"],
    test=fun_control["test"],
    target_column=fun_control["target_column"],
    horizon=fun_control["horizon"],
    oml_grace_period=fun_control["oml_grace_period"],
    metric=fun_control["metric_sklearn"],
)

```

```

from spotRiver.evaluation.eval_bml import plot_bml_oml_horizon_metrics, plot_bml_oml_horizon_predictions
df_labels=["default"]
plot_bml_oml_horizon_metrics(df_eval = [df_eval_default], log_y=False, df_labels=df_labels)
plot_bml_oml_horizon_predictions(df_true = [df_true_default[a:b]], target_column=target_column)

```



11.13 Get SPOT Results

```
from spotPython.hyperparameters.values import get_one_core_model_from_X
X = spot_tuner.to_all_dim(spot_tuner.min_X.reshape(1,-1))
model_spot = get_one_core_model_from_X(X, fun_control)
model_spot
```

```
HoeffdingAdaptiveTreeRegressor (
  grace_period=657
  max_depth=256
  delta=4e-08
  tau=0.048426
  leaf_prediction="adaptive"
  leaf_model=LinearRegression (
    optimizer=SGD (
      lr=Constant (
        learning_rate=0.01
      )
    )
    loss=Squared ()
    l2=0.
    l1=0.
    intercept_init=0.
    intercept_lr=Constant (
      learning_rate=0.01
    )
    clip_gradient=1e+12
    initializer=Zeros ()
  )
  model_selector_decay=0.970713
  nominal_attributes=None
  splitter=QOSplitter (
    radius=0.25
    allow_multiway_splits=False
  )
  min_samples_split=5
  bootstrap_sampling=1
  drift_window_threshold=166
  drift_detector=ADWIN (
    delta=0.002
    clock=32
```



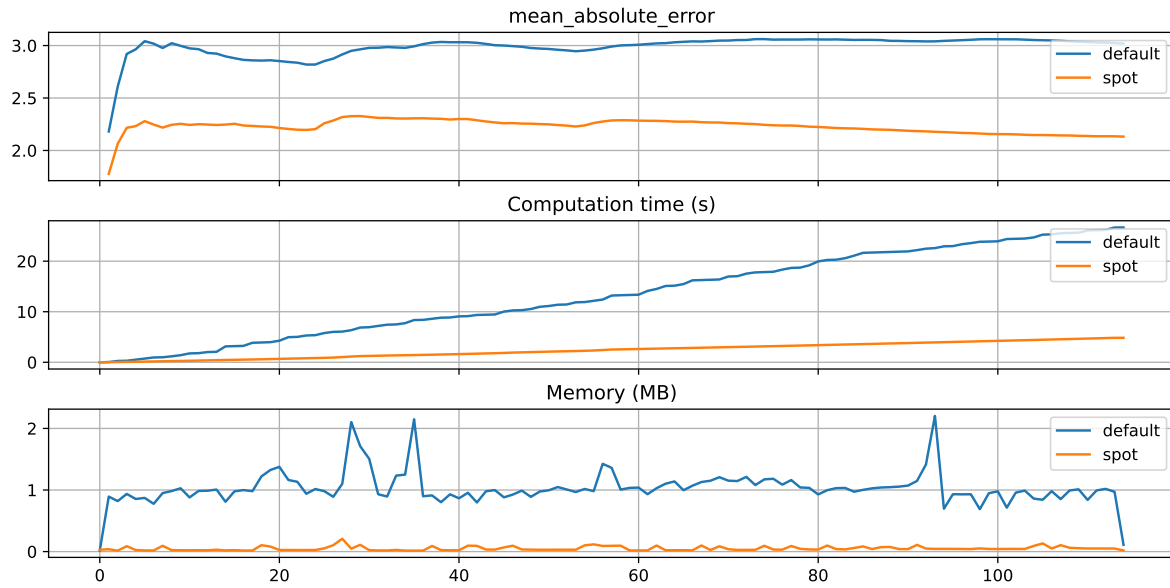
```

        max_buckets=5
        min_window_length=5
        grace_period=10
    )
    switch_significance=0.040371
    binary_split=0
    max_size=454.140654
    memory_estimate_period=910594
    stop_mem_management=1
    remove_poor_attrs=1
    merit_preprune=0
    seed=None
)

df_eval_spot, df_true_spot = eval_oml_horizon(
    model=model_spot,
    train=fun_control["train"],
    test=fun_control["test"],
    target_column=fun_control["target_column"],
    horizon=fun_control["horizon"],
    oml_grace_period=fun_control["oml_grace_period"],
    metric=fun_control["metric_sklearn"],
)

df_labels=["default", "spot"]
plot_bml_oml_horizon_metrics(df_eval = [df_eval_default, df_eval_spot], log_y=False, df_la

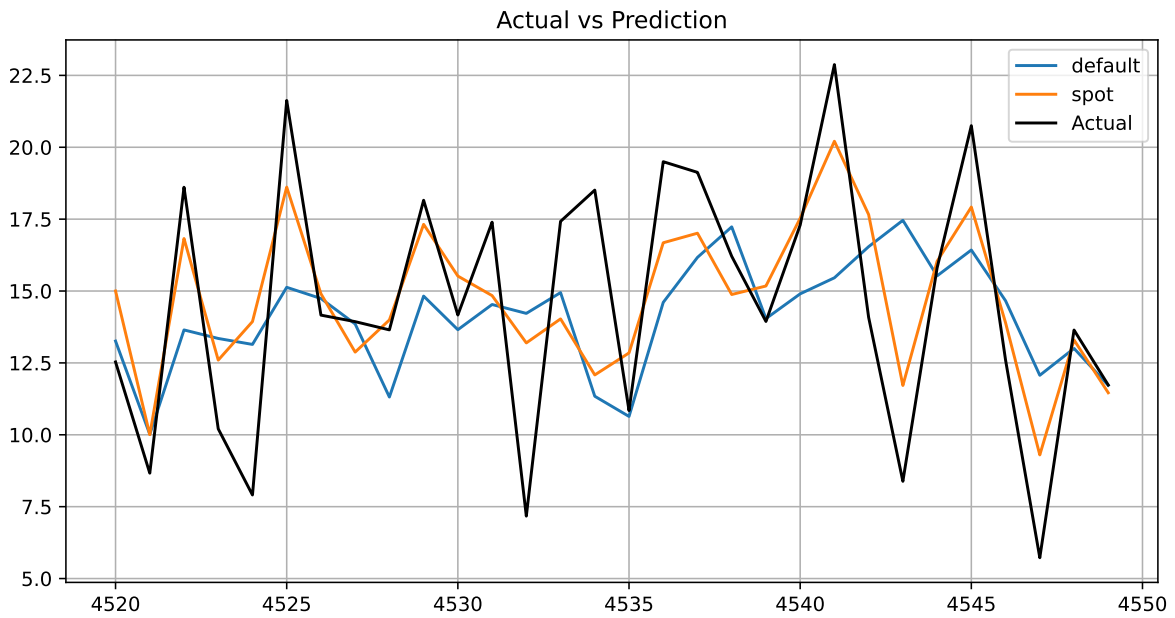
```



```

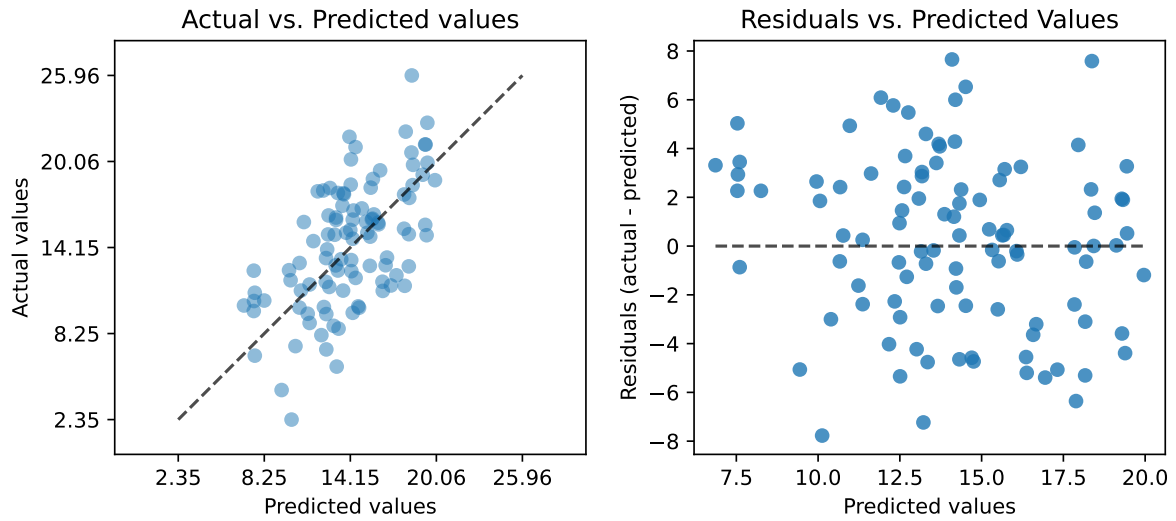
a = int(m/2)+20
b = int(m/2)+50
plot_bml_oml_horizon_predictions(df_true = [df_true_default[a:b], df_true_spot[a:b]], targ

```

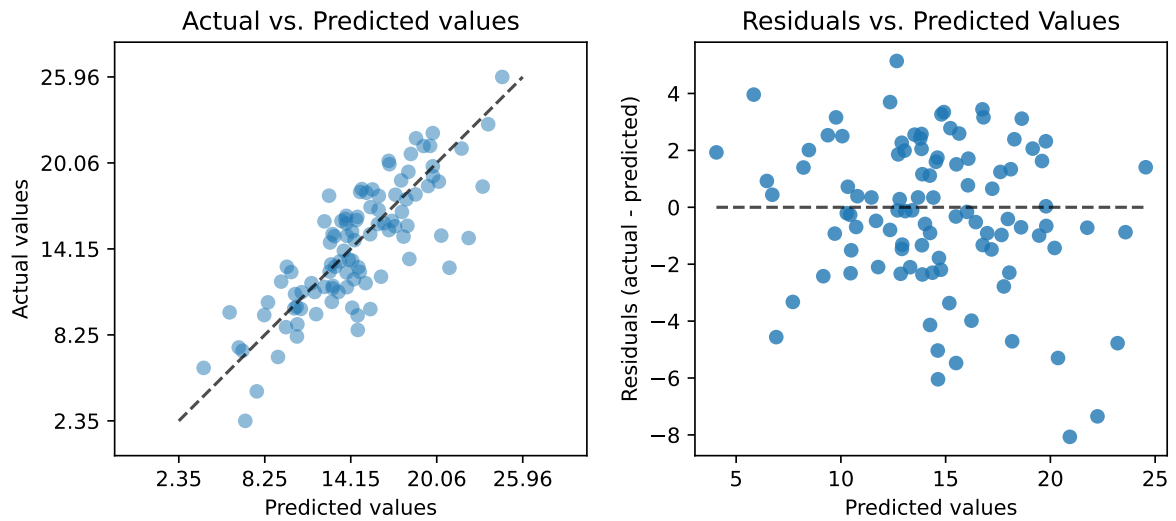


```
from spotPython.plot.validation import plot_actual_vs_predicted
plot_actual_vs_predicted(y_test=df_true_default["y"], y_pred=df_true_default["Prediction"])
plot_actual_vs_predicted(y_test=df_true_spot["y"], y_pred=df_true_spot["Prediction"], titl
```

Default



SPOT



11.14 Visualize Regression Trees

```
dataset_f = dataset.take(n_total)
for x, y in dataset_f:
    model_default.learn_one(x, y)
```

Caution: Large Trees

- Since the trees are large, the visualization is suppressed by default.
- To visualize the trees, uncomment the following line.

```
# model_default.draw()
```

```
model_default.summary
```

```
{'n_nodes': 35,
 'n_branches': 17,
 'n_leaves': 18,
 'n_active_leaves': 96,
 'n_inactive_leaves': 0,
 'height': 6,
 'total_observed_weight': 39002.0,
 'n_alternate_trees': 21,
 'n_pruned_alternate_trees': 6,
 'n_switch_alternate_trees': 2}
```

11.14.1 Spot Model

```
dataset_f = dataset.take(n_total)
for x, y in dataset_f:
    model_spot.learn_one(x, y)
```

Caution: Large Trees

- Since the trees are large, the visualization is suppressed by default.
- To visualize the trees, uncomment the following line.

```
# model_spot.draw()
```

```
model_spot.summary
```

```
{'n_nodes': 67,  
 'n_branches': 33,  
 'n_leaves': 34,  
 'n_active_leaves': 39,  
 'n_inactive_leaves': 0,  
 'height': 13,  
 'total_observed_weight': 39002.0,  
 'n_alternate_trees': 34,  
 'n_pruned_alternate_trees': 28,  
 'n_switch_alternate_trees': 1}
```

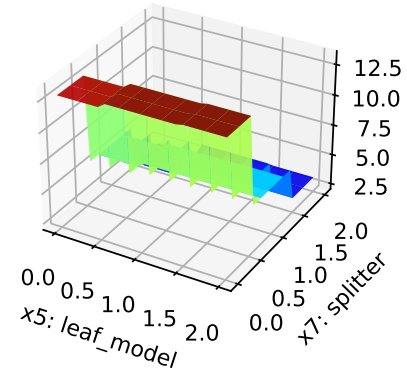
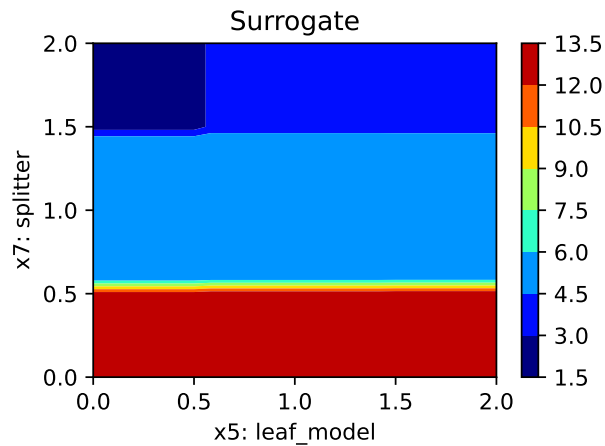
```
from spotPython.utils.eda import compare_two_tree_models  
print(compare_two_tree_models(model_default, model_spot))
```

Parameter	Default	Spot
n_nodes	35	67
n_branches	17	33
n_leaves	18	34
n_active_leaves	96	39
n_inactive_leaves	0	0
height	6	13
total_observed_weight	39002	39002
n_alternate_trees	21	34
n_pruned_alternate_trees	6	28
n_switch_alternate_trees	2	1

11.15 Detailed Hyperparameter Plots

```
filename = "./figures/" + experiment_name  
spot_tuner.plot_important_hyperparameter_contour(filename=filename)
```

```
leaf_model: 1.658600540059617  
splitter: 100.0
```



11.16 Parallel Coordinates Plots

```
spot_tuner.parallel_plot()
```

Unable to display output for mime type(s): text/html

Unable to display output for mime type(s): text/html

11.17 Plot all Combinations of Hyperparameters

- Warning: this may take a while.

```
PLOT_ALL = False
if PLOT_ALL:
    n = spot_tuner.k
    for i in range(n-1):
        for j in range(i+1, n):
            spot_tuner.plot_contour(i=i, j=j, min_z=min_z, max_z = max_z)
```

12 HPT: PyTorch With spotPython and Ray Tune on CIFAR10

In this tutorial, we will show how `spotPython` can be integrated into the PyTorch training workflow. It is based on the tutorial “Hyperparameter Tuning with Ray Tune” from the PyTorch documentation (PyTorch 2023a), which is an extension of the tutorial “Training a Classifier” (PyTorch 2023b) for training a CIFAR10 image classifier.

`spotPython` can be installed via `pip`¹.

```
!pip install spotPython
```


- Uncomment the following lines if you want to for (re-)installation the latest version of `spotPython` from `gitHub`.

```
# import sys
# !{sys.executable} -m pip install --upgrade build
# !{sys.executable} -m pip install --upgrade --force-reinstall spotPython
```

Results that refer to the `Ray Tune` package are taken from https://PyTorch.org/tutorials/beginner/hyperparameter_tuning_tutorial.html².

12.1 Step 1: Setup

Before we consider the detailed experimental setup, we select the parameters that affect run time, initial design size and the device that is used.

 **Caution:** Run time and initial design size should be increased for real experiments

- `MAX_TIME` is set to one minute for demonstration purposes. For real experiments, this should be increased to at least 1 hour.
- `INIT_SIZE` is set to 5 for demonstration purposes. For real experiments, this

¹Alternatively, the source code can be downloaded from `gitHub`: <https://github.com/sequential-parameter-optimization/spotPython>.

²We were not able to install `Ray Tune` on our system. Therefore, we used the results from the PyTorch tutorial.

should be increased to at least 10.

i Note: Device selection

- The device can be selected by setting the variable `DEVICE`.
- Since we are using a simple neural net, the setting "cpu" is preferred (on Mac).
- If you have a GPU, you can use "cuda:0" instead.
- If `DEVICE` is set to "auto" or None, `spotPython` will automatically select the device.
 - This might result in "mps" on Macs, which is not the best choice for simple neural nets.

```
MAX_TIME = 1
INIT_SIZE = 5
DEVICE = "auto" # "cpu"
PREFIX = "14-torch"
```

```
from spotPython.utils.device import getDevice
DEVICE = getDevice(DEVICE)
print(DEVICE)
```

mps

```
import warnings
warnings.filterwarnings("ignore")
```

12.2 Step 2: Initialization of the `fun_control` Dictionary

`spotPython` uses a Python dictionary for storing the information required for the hyperparameter tuning process. This dictionary is called `fun_control` and is initialized with the function `fun_control_init`. The function `fun_control_init` returns a skeleton dictionary. The dictionary is filled with the required information for the hyperparameter tuning process. It stores the hyperparameter tuning settings, e.g., the deep learning network architecture that should be tuned, the classification (or regression) problem, and the data that is used for the tuning. The dictionary is used as an input for the `SPOT` function.


```

from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_experiment_name, get_spot_tensorboard_path
from spotPython.utils.device import getDevice

experiment_name = get_experiment_name(prefix=PREFIX)

fun_control = fun_control_init(
    task="classification",
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    device=DEVICE,)

```

12.3 Step 3: PyTorch Data Loading

The data loading process is implemented in the same manner as described in the Section “Data loaders” in PyTorch (2023a). The data loaders are wrapped into the function `load_data_cifar10` which is identical to the function `load_data` in PyTorch (2023a). A global data directory is used, which allows sharing the data directory between different trials. The method `load_data_cifar10` is part of the `spotPython` package and can be imported from `spotPython.data.torchdata`.

In the following step, the test and train data are added to the dictionary `fun_control`.

```

from spotPython.data.torchdata import load_data_cifar10
train, test = load_data_cifar10()
n_samples = len(train)
# add the dataset to the fun_control
fun_control.update({
    "train": train,
    "test": test,
    "n_samples": n_samples})

```

Files already downloaded and verified

Files already downloaded and verified

12.4 Step 4: Specification of the Preprocessing Model

After the training and test data are specified and added to the `fun_control` dictionary, `spotPython` allows the specification of a data preprocessing pipeline, e.g., for the scaling

of the data or for the one-hot encoding of categorical variables. The preprocessing model is called `prep_model` (“preparation” or pre-processing) and includes steps that are not subject to the hyperparameter tuning process. The preprocessing model is specified in the `fun_control` dictionary. The preprocessing model can be implemented as a `sklearn` pipeline. The following code shows a typical preprocessing pipeline:

```
categorical_columns = ["cities", "colors"]
one_hot_encoder = OneHotEncoder(handle_unknown="ignore",
                                sparse_output=False)
prep_model = ColumnTransformer(
    transformers=[
        ("categorical", one_hot_encoder, categorical_columns),
    ],
    remainder=StandardScaler(),
)
```

Because the Ray Tune (`ray[tune]`) hyperparameter tuning as described in PyTorch (2023a) does not use a preprocessing model, the preprocessing model is set to `None` here.

```
prep_model = None
fun_control.update({"prep_model": prep_model})
```

12.5 Step 5: Select Model (algorithm) and `core_model_hyper_dict`

The same neural network model as implemented in the section “Configurable neural network” of the PyTorch tutorial (PyTorch 2023a) is used here. We will show the implementation from PyTorch (2023a) in Section 12.5.0.1 first, before the extended implementation with `spotPython` is shown in Section 12.5.0.2.

12.5.0.1 Implementing a Configurable Neural Network With Ray Tune

We used the same hyperparameters that are implemented as configurable in the PyTorch tutorial. We specify the layer sizes, namely 11 and 12, of the fully connected layers:

```
class Net(nn.Module):
    def __init__(self, l1=120, l2=84):
        super(Net, self).__init__()
        self.conv1 = nn.Conv2d(3, 6, 5)
```

```

self.pool = nn.MaxPool2d(2, 2)
self.conv2 = nn.Conv2d(6, 16, 5)
self.fc1 = nn.Linear(16 * 5 * 5, 11)
self.fc2 = nn.Linear(11, 12)
self.fc3 = nn.Linear(12, 10)

def forward(self, x):
    x = self.pool(F.relu(self.conv1(x)))
    x = self.pool(F.relu(self.conv2(x)))
    x = x.view(-1, 16 * 5 * 5)
    x = F.relu(self.fc1(x))
    x = F.relu(self.fc2(x))
    x = self.fc3(x)
    return x

```

The learning rate, i.e., `lr`, of the optimizer is made configurable, too:

```
optimizer = optim.SGD(net.parameters(), lr=config["lr"], momentum=0.9)
```

12.5.0.2 Implementing a Configurable Neural Network With `spotPython`

`spotPython` implements a class which is similar to the class described in the PyTorch tutorial. The class is called `Net_CIFAR10` and is implemented in the file `netcifar10.py`.

```

from torch import nn
import torch.nn.functional as F
import spotPython.torch.netcore as netcore

class Net_CIFAR10(netcore.Net_Core):
    def __init__(self, l1, l2, lr_mult, batch_size, epochs, k_folds, patience,
optimizer, sgd_momentum):
        super(Net_CIFAR10, self).__init__(
            lr_mult=lr_mult,
            batch_size=batch_size,
            epochs=epochs,
            k_folds=k_folds,
            patience=patience,
            optimizer=optimizer,
            sgd_momentum=sgd_momentum,
        )

```

```

self.conv1 = nn.Conv2d(3, 6, 5)
self.pool = nn.MaxPool2d(2, 2)
self.conv2 = nn.Conv2d(6, 16, 5)
self.fc1 = nn.Linear(16 * 5 * 5, 11)
self.fc2 = nn.Linear(11, 12)
self.fc3 = nn.Linear(12, 10)

def forward(self, x):
    x = self.pool(F.relu(self.conv1(x)))
    x = self.pool(F.relu(self.conv2(x)))
    x = x.view(-1, 16 * 5 * 5)
    x = F.relu(self.fc1(x))
    x = F.relu(self.fc2(x))
    x = self.fc3(x)
    return x

```

12.5.1 The Net_Core class

`Net_CIFAR10` inherits from the class `Net_Core` which is implemented in the file `netcore.py`. It implements the additional attributes that are common to all neural network models. The `Net_Core` class is implemented in the file `netcore.py`. It implements hyperparameters as attributes, that are not used by the `core_model`, e.g.:

- optimizer (`optimizer`),
- learning rate (`lr`),
- batch size (`batch_size`),
- epochs (`epochs`),
- k_folds (`k_folds`), and
- early stopping criterion “patience” (`patience`).

Users can add further attributes to the class. The class `Net_Core` is shown below.

```

from torch import nn

class Net_Core(nn.Module):
    def __init__(self, lr_mult, batch_size, epochs, k_folds, patience,
                  optimizer, sgd_momentum):
        super(Net_Core, self).__init__()
        self.lr_mult = lr_mult
        self.batch_size = batch_size

```

```

self.epochs = epochs
self.k_folds = k_folds
self.patience = patience
self.optimizer = optimizer
self.sgd_momentum = sgd_momentum

```

12.5.2 Comparison of the Approach Described in the PyTorch Tutorial With spotPython

Comparing the class `Net` from the PyTorch tutorial and the class `Net_CIFAR10` from `spotPython`, we see that the class `Net_CIFAR10` has additional attributes and does not inherit from `nn` directly. It adds an additional class, `Net_core`, that takes care of additional attributes that are common to all neural network models, e.g., the learning rate multiplier `lr_mult` or the batch size `batch_size`.

`spotPython`'s `core_model` implements an instance of the `Net_CIFAR10` class. In addition to the basic neural network model, the `core_model` can use these additional attributes. `spotPython` provides methods for handling these additional attributes to guarantee 100% compatibility with the PyTorch classes. The method `add_core_model_to_fun_control` adds the hyperparameters and additional attributes to the `fun_control` dictionary. The method is shown below.

```

from spotPython.torch.netcifar10 import Net_CIFAR10
from spotPython.data.torch_hyper_dict import TorchHyperDict
from spotPython.hyperparameters.values import add_core_model_to_fun_control
core_model = Net_CIFAR10
add_core_model_to_fun_control(core_model=core_model,
                             fun_control=fun_control,
                             hyper_dict=TorchHyperDict,
                             filename=None)

```

12.5.3 The Search Space: Hyperparameters

In Section 12.5.4, we first describe how to configure the search space with `ray[tune]` (as shown in PyTorch (2023a)) and then how to configure the search space with `spotPython` in -14.

12.5.4 Configuring the Search Space With Ray Tune

Ray Tune's search space can be configured as follows (PyTorch 2023a):

```

config = {
    "l1": tune.sample_from(lambda _: 2**np.random.randint(2, 9)),
    "l2": tune.sample_from(lambda _: 2**np.random.randint(2, 9)),
    "lr": tune.loguniform(1e-4, 1e-1),
    "batch_size": tune.choice([2, 4, 8, 16])
}

```

The `tune.sample_from()` function enables the user to define sample methods to obtain hyperparameters. In this example, the `l1` and `l2` parameters should be powers of 2 between 4 and 256, so either 4, 8, 16, 32, 64, 128, or 256. The `lr` (learning rate) should be uniformly sampled between 0.0001 and 0.1. Lastly, the batch size is a choice between 2, 4, 8, and 16.

At each trial, `ray[tune]` will randomly sample a combination of parameters from these search spaces. It will then train a number of models in parallel and find the best performing one among these. `ray[tune]` uses the `ASHAScheduler` which will terminate bad performing trials early.

12.5.5 Configuring the Search Space With spotPython

12.5.5.1 The `hyper_dict` Hyperparameters for the Selected Algorithm

`spotPython` uses JSON files for the specification of the hyperparameters. Users can specify their individual JSON files, or they can use the JSON files provided by `spotPython`. The JSON file for the `core_model` is called `torch_hyper_dict.json`.

In contrast to `ray[tune]`, `spotPython` can handle numerical, boolean, and categorical hyperparameters. They can be specified in the JSON file in a similar way as the numerical hyperparameters as shown below. Each entry in the JSON file represents one hyperparameter with the following structure: `type`, `default`, `transform`, `lower`, and `upper`.

```

"factor_hyperparameter": {
    "levels": ["A", "B", "C"],
    "type": "factor",
    "default": "B",
    "transform": "None",
    "core_model_parameter_type": "str",
    "lower": 0,
    "upper": 2},

```

The corresponding entries for the `core_model` class are shown below.

```

fun_control['core_model_hyper_dict']

```

```

{'l1': {'type': 'int',
       'default': 5,
       'transform': 'transform_power_2_int',
       'lower': 2,
       'upper': 9},
 'l2': {'type': 'int',
       'default': 5,
       'transform': 'transform_power_2_int',
       'lower': 2,
       'upper': 9},
 'lr_mult': {'type': 'float',
             'default': 1.0,
             'transform': 'None',
             'lower': 0.1,
             'upper': 10.0},
 'batch_size': {'type': 'int',
                'default': 4,
                'transform': 'transform_power_2_int',
                'lower': 1,
                'upper': 4},
 'epochs': {'type': 'int',
            'default': 3,
            'transform': 'transform_power_2_int',
            'lower': 3,
            'upper': 4},
 'k_folds': {'type': 'int',
             'default': 1,
             'transform': 'None',
             'lower': 1,
             'upper': 1},
 'patience': {'type': 'int',
              'default': 5,
              'transform': 'None',
              'lower': 2,
              'upper': 10},
 'optimizer': {'levels': ['Adadelata',
                          'Adagrad',
                          'Adam',
                          'AdamW',
                          'SparseAdam',
                          'Adamax',
                          'ASGD',
                          'NAdam'],

```

```

'RAAdam',
'RMSprop',
'Rprop',
'SGD'],
'type': 'factor',
'default': 'SGD',
'transform': 'None',
'class_name': 'torch.optim',
'core_model_parameter_type': 'str',
'lower': 0,
'upper': 12},
'sgd_momentum': {'type': 'float',
'default': 0.0,
'transform': 'None',
'lower': 0.0,
'upper': 1.0}}

```

12.6 Step 6: Modify `hyper_dict` Hyperparameters for the Selected Algorithm aka `core_model`

Ray tune (PyTorch 2023a) does not provide a way to change the specified hyperparameters without re-compilation. However, `spotPython` provides functions for modifying the hyperparameters, their bounds and factors as well as for activating and de-activating hyperparameters without re-compilation of the Python source code. These functions are described in the following.

12.6.0.1 Modify `hyper_dict` Hyperparameters for the Selected Algorithm aka `core_model`

After specifying the model, the corresponding hyperparameters, their types and bounds are loaded from the JSON file `torch_hyper_dict.json`. After loading, the user can modify the hyperparameters, e.g., the bounds. `spotPython` provides a simple rule for de-activating hyperparameters: If the lower and the upper bound are set to identical values, the hyperparameter is de-activated. This is useful for the hyperparameter tuning, because it allows to specify a hyperparameter in the JSON file, but to de-activate it in the `fun_control` dictionary. This is done in the next step.

12.6.0.2 Modify Hyperparameters of Type numeric and integer (boolean)

Since the hyperparameter `k_folds` is not used in the PyTorch tutorial, it is de-activated here by setting the lower and upper bound to the same value. Note, `k_folds` is of type “integer”.

```
from spotPython.hyperparameters.values import modify_hyper_parameter_bounds
modify_hyper_parameter_bounds(fun_control,
    "batch_size", bounds=[1, 5])
modify_hyper_parameter_bounds(fun_control,
    "k_folds", bounds=[0, 0])
modify_hyper_parameter_bounds(fun_control,
    "patience", bounds=[3, 3])
```

12.6.0.3 Modify Hyperparameter of Type factor

In a similar manner as for the numerical hyperparameters, the categorical hyperparameters can be modified. New configurations can be chosen by adding or deleting levels. For example, the hyperparameter `optimizer` can be re-configured as follows:

In the following setting, two optimizers ("SGD" and "Adam") will be compared during the `spotPython` hyperparameter tuning. The hyperparameter `optimizer` is active.

```
from spotPython.hyperparameters.values import modify_hyper_parameter_levels
modify_hyper_parameter_levels(fun_control,
    "optimizer", ["SGD", "Adam"])
```

The hyperparameter `optimizer` can be de-activated by choosing only one value (level), here: "SGD".

```
modify_hyper_parameter_levels(fun_control, "optimizer", ["SGD"])
```

As discussed in Section 12.6.1, there are some issues with the LBFGS optimizer. Therefore, the usage of the LBFGS optimizer is not deactivated in `spotPython` by default. However, the LBFGS optimizer can be activated by adding it to the list of optimizers. `Rprop` was removed, because it does perform very poorly (as some pre-tests have shown). However, it can also be activated by adding it to the list of optimizers. Since `SparseAdam` does not support dense gradients, `Adam` was used instead. Therefore, there are 10 default optimizers:

```
modify_hyper_parameter_levels(fun_control, "optimizer",
    ["Adadelta", "Adagrad", "Adam", "AdamW", "Adamax", "ASGD",
    "NAdam", "RAdam", "RMSprop", "SGD"])
```

12.6.1 Optimizers

Table 12.1 shows some of the optimizers available in PyTorch:

a denotes (0.9,0.999), b (0.5,1.2), and c (1e-6, 50), respectively. R denotes required, but unspecified. “m” denotes momentum, “w_d” weight_decay, “d” dampening, “n” nesterov, “r” rho, “l_s” learning rate for scaling delta, “l_d” lr_decay, “b” betas, “l” lambd, “a” alpha, “m_d” for momentum_decay, “e” etas, and “s_s” for step_sizes.

Table 12.1: Optimizers available in PyTorch (selection). The default values are shown in the table.

Optimizer	lr	m	w_d	d	n	r	l_s	l_d	b	l	a	m_d	e	s_s
Adadelta	-	-	0.	-	-	0.9	1.	-	-	-	-	-	-	-
Adagrad	1e-2	-	0.	-	-	-	-	0.	-	-	-	-	-	-
Adam	1e-3	-	0.	-	-	-	-	-	a	-	-	-	-	-
AdamW	1e-3	-	1e-2	-	-	-	-	-	a	-	-	-	-	-
SparseAdam	1e-3	-	-	-	-	-	-	-	a	-	-	-	-	-
Adamax	2e-3	-	0.	-	-	-	-	-	a	-	-	-	-	-
ASGD	1e-2	.9	0.	-	F	-	-	-	-	1e-4	.75	-	-	-
LBFGS	1.	-	-	-	-	-	-	-	-	-	-	-	-	-
NAdam	2e-3	-	0.	-	-	-	-	-	a	-	-	0	-	-
RAdam	1e-3	-	0.	-	-	-	-	-	a	-	-	-	-	-
RMSprop	1e-2	0.	0.	-	-	-	-	-	a	-	-	-	-	-
Rprop	1e-2	-	-	-	-	-	-	-	-	-	b	c	-	-
SGD	R	0.	0.	0.	F	-	-	-	-	-	-	-	-	-

spotPython implements an `optimization` handler that maps the optimizer names to the corresponding PyTorch optimizers.

A note on LBFGS

We recommend deactivating PyTorch’s LBFGS optimizer, because it does not perform very well. The PyTorch documentation, see <https://pytorch.org/docs/stable/generated/torch.optim.LBFGS.html#torch.optim.LBFGS>, states:

This is a very memory intensive optimizer (it requires additional `param_bytes * (history_size + 1)` bytes). If it doesn’t fit in memory try reducing the history size, or use a different algorithm.

Furthermore, the LBFGS optimizer is not compatible with the PyTorch tutorial. The reason is that the LBFGS optimizer requires the `closure` function, which is not implemented in the PyTorch tutorial. Therefore, the LBFGS optimizer is recommended here.

Since there are ten optimizers in the portfolio, it is not recommended tuning the hyperparameters that effect one single optimizer only.

i A note on the learning rate

`spotPython` provides a multiplier for the default learning rates, `lr_mult`, because optimizers use different learning rates. Using a multiplier for the learning rates might enable a simultaneous tuning of the learning rates for all optimizers. However, this is not recommended, because the learning rates are not comparable across optimizers. Therefore, we recommend fixing the learning rate for all optimizers if multiple optimizers are used. This can be done by setting the lower and upper bounds of the learning rate multiplier to the same value as shown below.

Thus, the learning rate, which affects the SGD optimizer, will be set to a fixed value. We choose the default value of `1e-3` for the learning rate, because it is used in other PyTorch examples (it is also the default value used by `spotPython` as defined in the `optimizer_handler()` method). We recommend tuning the learning rate later, when a reduced set of optimizers is fixed. Here, we will demonstrate how to select in a screening phase the optimizers that should be used for the hyperparameter tuning.

For the same reason, we will fix the `sgd_momentum` to 0.9.

```
modify_hyper_parameter_bounds(fun_control,
                              "lr_mult", bounds=[1.0, 1.0])
modify_hyper_parameter_bounds(fun_control,
                              "sgd_momentum", bounds=[0.9, 0.9])
```

12.7 Step 7: Selection of the Objective (Loss) Function

12.7.1 Evaluation: Data Splitting

The evaluation procedure requires the specification of the way how the data is split into a train and a test set and the loss function (and a metric). As a default, `spotPython` provides a standard hold-out data split and cross validation.

12.7.2 Hold-out Data Split

If a hold-out data split is used, the data will be partitioned into a training, a validation, and a test data set. The split depends on the setting of the `eval` parameter. If `eval` is set to `train_hold_out`, one data set, usually the original training data set, is split into a new

training and a validation data set. The training data set is used for training the model. The validation data set is used for the evaluation of the hyperparameter configuration and early stopping to prevent overfitting. In this case, the original test data set is not used.

i Note

`spotPython` returns the hyperparameters of the machine learning and deep learning models, e.g., number of layers, learning rate, or optimizer, but not the model weights. Therefore, after the SPOT run is finished, the corresponding model with the optimized architecture has to be trained again with the best hyperparameter configuration. The training is performed on the training data set. The test data set is used for the final evaluation of the model.

Summarizing, the following splits are performed in the hold-out setting:

1. Run `spotPython` with `eval` set to `train_hold_out` to determine the best hyperparameter configuration.
2. Train the model with the best hyperparameter configuration (“architecture”) on the training data set: `train_tuned(model_spot, train, "model_spot.pt")`.
3. Test the model on the test data: `test_tuned(model_spot, test, "model_spot.pt")`

These steps will be exemplified in the following sections.

In addition to this `hold-out` setting, `spotPython` provides another hold-out setting, where an explicit test data is specified by the user that will be used as the validation set. To choose this option, the `eval` parameter is set to `test_hold_out`. In this case, the training data set is used for the model training. Then, the explicitly defined test data set is used for the evaluation of the hyperparameter configuration (the validation).

12.7.3 Cross-Validation

The cross validation setting is used by setting the `eval` parameter to `train_cv` or `test_cv`. In both cases, the data set is split into k folds. The model is trained on $k - 1$ folds and evaluated on the remaining fold. This is repeated k times, so that each fold is used exactly once for evaluation. The final evaluation is performed on the test data set. The cross validation setting is useful for small data sets, because it allows to use all data for training and evaluation. However, it is computationally expensive, because the model has to be trained k times.

i Note

Combinations of the above settings are possible, e.g., cross validation can be used for training and hold-out for evaluation or *vice versa*. Also, cross validation can be used

for training and testing. Because cross validation is not used in the PyTorch tutorial (PyTorch 2023a), it is not considered further here.

12.7.4 Overview of the Evaluation Settings

12.7.4.1 Settings for the Hyperparameter Tuning

An overview of the training evaluations is shown in Table 12.2. "train_cv" and "test_cv" use `sklearn.model_selection.KFold()` internally. More details on the data splitting are provided in Section 18.14 (in the Appendix).

Table 12.2: Overview of the evaluation settings.

eval	train	test	function	comment
"train_hold_out" ✓			<code>train_one_epoch()</code> , <code>validate_one_epoch()</code> for early stopping	splits the train data set internally
"test_hold_out" ✓	✓	✓	<code>train_one_epoch()</code> , <code>validate_one_epoch()</code> for early stopping	use the test data set for <code>validate_one_epoch()</code>
"train_cv"	✓		<code>evaluate_cv(net, train)</code>	CV using the train data set
"test_cv"		✓	<code>evaluate_cv(net, test)</code>	CV using the test data set . Identical to "train_cv", uses only test data.

12.7.4.2 Settings for the Final Evaluation of the Tuned Architecture

12.7.4.2.1 Training of the Tuned Architecture

`train_tuned(model, train)`: train the model with the best hyperparameter configuration (or simply the default) on the training data set. It splits the `traindata` into new `train` and `validation` sets using `create_train_val_data_loaders()`, which calls `torch.utils.data.random_split()` internally. Currently, 60% of the data is used for training and 40% for validation. The `train` data is used for training the model with `train_hold_out()`. The `validation` data is used for early stopping using `validate_fold_or_hold_out()` on the validation data set.

12.7.4.2.2 Testing of the Tuned Architecture

`test_tuned(model, test)`: test the model on the test data set. No data splitting is performed. The (trained) model is evaluated using the `validate_fold_or_hold_out()` function. Note: During training, "shuffle" is set to `True`, whereas during testing, "shuffle" is set to `False`.

Section [18.14.1.4](#) describes the final evaluation of the tuned architecture.

```
fun_control.update({
    "eval": "train_hold_out",
    "path": "torch_model.pt",
    "shuffle": True})
```

12.7.5 Evaluation: Loss Functions and Metrics

The key "loss_function" specifies the loss function which is used during the optimization. There are several different loss functions under PyTorch's `nn` package. For example, a simple loss is `MSELoss`, which computes the mean-squared error between the output and the target. In this tutorial we will use `CrossEntropyLoss`, because it is also used in the PyTorch tutorial.

```
from torch.nn import CrossEntropyLoss
loss_function = CrossEntropyLoss()
fun_control.update({"loss_function": loss_function})
```

In addition to the loss functions, `spotPython` provides access to a large number of metrics.

- The key "metric_sklearn" is used for metrics that follow the `scikit-learn` conventions.
- The key "river_metric" is used for the river based evaluation (Montiel et al. 2021) via `eval_oml_iter_progressive`, and
- the key "metric_torch" is used for the metrics from `TorchMetrics`.

`TorchMetrics` is a collection of more than 90 PyTorch metrics, see <https://torchmetrics.readthedocs.io/en/latest/>. Because the PyTorch tutorial uses the accuracy as metric, we use the same metric here. Currently, accuracy is computed in the tutorial's example code. We will use `TorchMetrics` instead, because it offers more flexibility, e.g., it can be used for regression and classification. Furthermore, `TorchMetrics` offers the following advantages:

- * A standardized interface to increase reproducibility
- * Reduces Boilerplate
- * Distributed-training compatible
- * Rigorously tested
- * Automatic accumulation over batches

* Automatic synchronization between multiple devices

Therefore, we set

```
import torchmetrics
metric_torch = torchmetrics.Accuracy(task="multiclass", num_classes=10).to(fun_control["de
fun_control.update({"metric_torch": metric_torch})
```

12.8 Step 8: Calling the SPOT Function

12.8.1 Preparing the SPOT Call

The following code passes the information about the parameter ranges and bounds to `spot`.

```
from spotPython.hyperparameters.values import (
    get_var_type,
    get_var_name,
    get_bound_values
)
var_type = get_var_type(fun_control)
var_name = get_var_name(fun_control)

lower = get_bound_values(fun_control, "lower")
upper = get_bound_values(fun_control, "upper")
```

Now, the dictionary `fun_control` contains all information needed for the hyperparameter tuning. Before the hyperparameter tuning is started, it is recommended to take a look at the experimental design. The method `gen_design_table` generates a design table as follows:

```
from spotPython.utils.eda import gen_design_table
print(gen_design_table(fun_control))
```

name	type	default	lower	upper	transform
l1	int	5	2	9	transform_power_2_int
l2	int	5	2	9	transform_power_2_int
lr_mult	float	1.0	1	1	None
batch_size	int	4	1	5	transform_power_2_int
epochs	int	3	3	4	transform_power_2_int
k_folds	int	1	0	0	None

patience	int	5	3	3	None	
optimizer	factor	SGD	0	9	None	
SGD_momentum	float	0.0	0.9	0.9	None	

This allows to check if all information is available and if the information is correct. `?@tbl-design` shows the experimental design for the hyperparameter tuning. The table shows the hyperparameters, their types, default values, lower and upper bounds, and the transformation function. The transformation function is used to transform the hyperparameter values from the unit hypercube to the original domain. The transformation function is applied to the hyperparameter values before the evaluation of the objective function. Hyperparameter transformations are shown in the column “transform”, e.g., the `l1` default is 5, which results in the value $2^5 = 32$ for the network, because the transformation `transform_power_2_int` was selected in the JSON file. The default value of the `batch_size` is set to 4, which results in a batch size of $2^4 = 16$.

12.8.2 The Objective Function `fun_torch`

The objective function `fun_torch` is selected next. It implements an interface from PyTorch’s training, validation, and testing methods to `spotPython`.

```
from spotPython.fun.hypertorch import HyperTorch
fun = HyperTorch().fun_torch
```

12.8.3 Using Default Hyperparameters or Results from Previous Runs

We add the default setting to the initial design:

```
from spotPython.hyperparameters.values import get_default_hyperparameters_as_array
X_start = get_default_hyperparameters_as_array(fun_control)
```

12.8.4 Starting the Hyperparameter Tuning

The `spotPython` hyperparameter tuning is started by calling the `Spot` function. Here, we will run the tuner for approximately 30 minutes (`max_time`). Note: the initial design is always evaluated in the `spotPython` run. As a consequence, the run may take longer than specified by `max_time`, because the evaluation time of initial design (here: `init_size`, 10 points) is performed independently of `max_time`. During the run, results from the training is shown. These results can be visualized with Tensorboard as will be shown in Section 12.9.


```

from spotPython.spot import spot
from math import inf
import numpy as np
spot_tuner = spot.Spot(fun=fun,
                       lower = lower,
                       upper = upper,
                       fun_evals = inf,
                       max_time = MAX_TIME,
                       tolerance_x = np.sqrt(np.spacing(1)),
                       var_type = var_type,
                       var_name = var_name,
                       show_progress= True,
                       fun_control = fun_control,
                       design_control={"init_size": INIT_SIZE},
                       surrogate_control={"noise": True,
                                         "cod_type": "norm",
                                         "min_theta": -4,
                                         "max_theta": 3,
                                         "n_theta": len(var_name),
                                         "model_fun_evals": 10_000
                                         })

spot_tuner.run(X_start=X_start)

```

config: {'l1': 128, 'l2': 8, 'lr_mult': 1.0, 'batch_size': 32, 'epochs': 16, 'k_folds': 0, 'j': 1}
Epoch: 1 |

MulticlassAccuracy: 0.3829999864101410 | Loss: 1.6553161247253418 | Acc: 0.3830000000000000.
Epoch: 2 |

MulticlassAccuracy: 0.4560500085353851 | Loss: 1.4838879354476928 | Acc: 0.4560500000000000.
Epoch: 3 |

MulticlassAccuracy: 0.4982999861240387 | Loss: 1.3767267515182495 | Acc: 0.4983000000000000.
Epoch: 4 |

MulticlassAccuracy: 0.5091999769210815 | Loss: 1.3384420643806458 | Acc: 0.5092000000000000.
Epoch: 5 |

MulticlassAccuracy: 0.5468999743461609 | Loss: 1.2707180584907531 | Acc: 0.5469000000000001.
Epoch: 6 |

MulticlassAccuracy: 0.5637500286102295 | Loss: 1.2211183403015138 | Acc: 0.5637500000000000.
Epoch: 7 |

MulticlassAccuracy: 0.5626000165939331 | Loss: 1.2280995187759400 | Acc: 0.5626000000000000.
Epoch: 8 |

MulticlassAccuracy: 0.5885000228881836 | Loss: 1.1640188122749329 | Acc: 0.5885000000000000.
Epoch: 9 |

MulticlassAccuracy: 0.5988500118255615 | Loss: 1.1422295256614685 | Acc: 0.5988500000000000.
Epoch: 10 |

MulticlassAccuracy: 0.6029000282287598 | Loss: 1.1518854703903199 | Acc: 0.6029000000000000.
Epoch: 11 |

MulticlassAccuracy: 0.6004499793052673 | Loss: 1.1602988395690919 | Acc: 0.6004500000000000.
Epoch: 12 |

MulticlassAccuracy: 0.6036000251770020 | Loss: 1.1707189303874970 | Acc: 0.6036000000000000.
Early stopping at epoch 11
Returned to Spot: Validation loss: 1.170718930387497

config: {'l1': 16, 'l2': 16, 'lr_mult': 1.0, 'batch_size': 8, 'epochs': 8, 'k_folds': 0, 'pa
Epoch: 1 |

MulticlassAccuracy: 0.4374000132083893 | Loss: 1.5172192733287810 | Acc: 0.4374000000000000.
Epoch: 2 |

MulticlassAccuracy: 0.4927499890327454 | Loss: 1.3796086355447770 | Acc: 0.4927500000000000.
Epoch: 3 |

MulticlassAccuracy: 0.4817999899387360 | Loss: 1.4559810544162988 | Acc: 0.4818000000000000.
Epoch: 4 |

MulticlassAccuracy: 0.5187500119209290 | Loss: 1.3598954739451408 | Acc: 0.5187500000000000.
Epoch: 5 |

MulticlassAccuracy: 0.5167499780654907 | Loss: 1.3375289655864240 | Acc: 0.5167500000000000.
Epoch: 6 |

MulticlassAccuracy: 0.5430999994277954 | Loss: 1.2862036019682883 | Acc: 0.5431000000000000.
Epoch: 7 |

MulticlassAccuracy: 0.5409500002861023 | Loss: 1.3087708984255790 | Acc: 0.5409500000000000.
Epoch: 8 |

MulticlassAccuracy: 0.5330500006675720 | Loss: 1.3348787559032440 | Acc: 0.5330500000000000.
Returned to Spot: Validation loss: 1.334878755903244

config: {'l1': 256, 'l2': 128, 'lr_mult': 1.0, 'batch_size': 2, 'epochs': 16, 'k_folds': 0,
Epoch: 1 |

MulticlassAccuracy: 0.0958999991416931 | Loss: 2.3086879378318788 | Acc: 0.0959000000000000.
Epoch: 2 |

MulticlassAccuracy: 0.0987000018358231 | Loss: 2.3107500162124635 | Acc: 0.0987000000000000.
Epoch: 3 |

MulticlassAccuracy: 0.0958499982953072 | Loss: 2.3054560756921769 | Acc: 0.0958500000000000.
Epoch: 4 |

MulticlassAccuracy: 0.1013000011444092 | Loss: 2.3091404372692108 | Acc: 0.1013000000000000.
Epoch: 5 |

MulticlassAccuracy: 0.0958499982953072 | Loss: 2.3109532579421996 | Acc: 0.0958500000000000.
Epoch: 6 |

MulticlassAccuracy: 0.0987000018358231 | Loss: 2.3080131625890732 | Acc: 0.0987000000000000.
Early stopping at epoch 5
Returned to Spot: Validation loss: 2.308013162589073

config: {'l1': 8, 'l2': 32, 'lr_mult': 1.0, 'batch_size': 4, 'epochs': 8, 'k_folds': 0, 'pat.
Epoch: 1 |

MulticlassAccuracy: 0.3769499957561493 | Loss: 1.6615093360960485 | Acc: 0.3769500000000000.
Epoch: 2 |

MulticlassAccuracy: 0.4517500102519989 | Loss: 1.5121046626687049 | Acc: 0.4517500000000000.
Epoch: 3 |

MulticlassAccuracy: 0.4941000044345856 | Loss: 1.3761642190143466 | Acc: 0.4941000000000000.
Epoch: 4 |

MulticlassAccuracy: 0.5034499764442444 | Loss: 1.3687846368297933 | Acc: 0.5034500000000000.
Epoch: 5 |

MulticlassAccuracy: 0.5278000235557556 | Loss: 1.3216290992997586 | Acc: 0.5278000000000000.
Epoch: 6 |

MulticlassAccuracy: 0.5368499755859375 | Loss: 1.3035639314051253 | Acc: 0.5368500000000000.
Epoch: 7 |

MulticlassAccuracy: 0.5354999899864197 | Loss: 1.3129267637871205 | Acc: 0.5355000000000000.
Epoch: 8 |

MulticlassAccuracy: 0.5587000250816345 | Loss: 1.2531040177643300 | Acc: 0.5587000000000000.
Returned to Spot: Validation loss: 1.25310401776433

config: {'l1': 64, 'l2': 512, 'lr_mult': 1.0, 'batch_size': 16, 'epochs': 16, 'k_folds': 0,
Epoch: 1 |

MulticlassAccuracy: 0.4729999899864197 | Loss: 1.4367030944347381 | Acc: 0.4730000000000000.
Epoch: 2 |

MulticlassAccuracy: 0.5012500286102295 | Loss: 1.3735576897144317 | Acc: 0.5012500000000000.
Epoch: 3 |

MulticlassAccuracy: 0.5195000171661377 | Loss: 1.3156053163051604 | Acc: 0.5195000000000000.
Epoch: 4 |

MulticlassAccuracy: 0.5393499732017517 | Loss: 1.2678873259544372 | Acc: 0.5393500000000000.
Epoch: 5 |

MulticlassAccuracy: 0.5470499992370605 | Loss: 1.2542407387256622 | Acc: 0.5470500000000000.
Epoch: 6 |

MulticlassAccuracy: 0.5583000183105469 | Loss: 1.2251633467197418 | Acc: 0.5583000000000000.
Epoch: 7 |

MulticlassAccuracy: 0.5622500181198120 | Loss: 1.2151848752498626 | Acc: 0.5622500000000000.
Epoch: 8 |

MulticlassAccuracy: 0.5647500157356262 | Loss: 1.2077777709007262 | Acc: 0.5647500000000000.
Epoch: 9 |

MulticlassAccuracy: 0.5739499926567078 | Loss: 1.1943912165403365 | Acc: 0.5739500000000000.
Epoch: 10 |

MulticlassAccuracy: 0.5769500136375427 | Loss: 1.1811906848907470 | Acc: 0.5769500000000000.
Epoch: 11 |

MulticlassAccuracy: 0.5766999721527100 | Loss: 1.1821756593227386 | Acc: 0.5767000000000000.
Epoch: 12 |

MulticlassAccuracy: 0.5859000086784363 | Loss: 1.1639863549709319 | Acc: 0.5859000000000000.
Epoch: 13 |

MulticlassAccuracy: 0.5894500017166138 | Loss: 1.1575640406370162 | Acc: 0.5894500000000000.
Epoch: 14 |

MulticlassAccuracy: 0.5881000161170959 | Loss: 1.1576142327308654 | Acc: 0.5881000000000000.
Epoch: 15 |

MulticlassAccuracy: 0.5943499803543091 | Loss: 1.1511327358484269 | Acc: 0.5943500000000000.
Epoch: 16 |

MulticlassAccuracy: 0.5938000082969666 | Loss: 1.1506362612009049 | Acc: 0.5938000000000000.
Returned to Spot: Validation loss: 1.150636261200905

config: {'l1': 64, 'l2': 256, 'lr_mult': 1.0, 'batch_size': 16, 'epochs': 16, 'k_folds': 0,
Epoch: 1 |

MulticlassAccuracy: 0.4441500008106232 | Loss: 1.5163077456474303 | Acc: 0.4441500000000000.
Epoch: 2 |

MulticlassAccuracy: 0.4684500098228455 | Loss: 1.4445160336494445 | Acc: 0.4684500000000000.
Epoch: 3 |

MulticlassAccuracy: 0.4887999892234802 | Loss: 1.4072586935997009 | Acc: 0.4888000000000000.
Epoch: 4 |

MulticlassAccuracy: 0.4977000057697296 | Loss: 1.3786401181697845 | Acc: 0.4977000000000000.
Epoch: 5 |

MulticlassAccuracy: 0.5064499974250793 | Loss: 1.3515173541545868 | Acc: 0.5064500000000000.
Epoch: 6 |

MulticlassAccuracy: 0.5199000239372253 | Loss: 1.3313189662456513 | Acc: 0.5199000000000000.
Epoch: 7 |

MulticlassAccuracy: 0.5317000150680542 | Loss: 1.3071723269462585 | Acc: 0.5317000000000000.
Epoch: 8 |

MulticlassAccuracy: 0.5350999832153320 | Loss: 1.3025408359050750 | Acc: 0.5351000000000000.
Epoch: 9 |

MulticlassAccuracy: 0.5384500026702881 | Loss: 1.2851462400913238 | Acc: 0.5384500000000000.
Epoch: 10 |

MulticlassAccuracy: 0.5464500188827515 | Loss: 1.2660254968643188 | Acc: 0.5464500000000000.
Epoch: 11 |

MulticlassAccuracy: 0.5476499795913696 | Loss: 1.2699793147087097 | Acc: 0.5476500000000000.
Epoch: 12 |

MulticlassAccuracy: 0.5588999986648560 | Loss: 1.2439207300186157 | Acc: 0.5589000000000000.
Epoch: 13 |

MulticlassAccuracy: 0.5522500276565552 | Loss: 1.2513182124137878 | Acc: 0.5522500000000000.
Epoch: 14 |

MulticlassAccuracy: 0.5628499984741211 | Loss: 1.2343774038791657 | Acc: 0.5628500000000000.
Epoch: 15 |

MulticlassAccuracy: 0.5617499947547913 | Loss: 1.2356968837261200 | Acc: 0.5617500000000000.
Epoch: 16 |

```
MulticlassAccuracy: 0.5662500262260437 | Loss: 1.2208059081315994 | Acc: 0.5662500000000000.  
Returned to Spot: Validation loss: 1.2208059081315994  
spotPython tuning: 1.150636261200905 [#####] 100.00% Done...
```

```
<spotPython.spot.spot.Spot at 0x2c709bd60>
```

12.9 Step 9: Tensorboard

The textual output shown in the console (or code cell) can be visualized with Tensorboard.

12.9.1 Tensorboard: Start Tensorboard

Start TensorBoard through the command line to visualize data you logged. Specify the root log directory as used in `fun_control = fun_control_init(task="regression", tensorboard_path="runs/24_spot_torch_regression")` as the `tensorboard_path`. The argument `logdir` points to directory where TensorBoard will look to find event files that it can display. TensorBoard will recursively walk the directory structure rooted at `logdir`, looking for `.tfevents.` files.

```
tensorboard --logdir=runs
```

Go to the URL it provides or to <http://localhost:6006/>. The following figures show some screenshots of Tensorboard.

12.9.2 Saving the State of the Notebook

The state of the notebook can be saved and reloaded as follows:

```
import pickle  
SAVE = False  
LOAD = False  
  
if SAVE:  
    result_file_name = "res_" + experiment_name + ".pkl"  
    with open(result_file_name, 'wb') as f:  
        pickle.dump(spot_tuner, f)  
  
if LOAD:  
    result_file_name = "add_the_name_of_the_result_file_here.pkl"
```

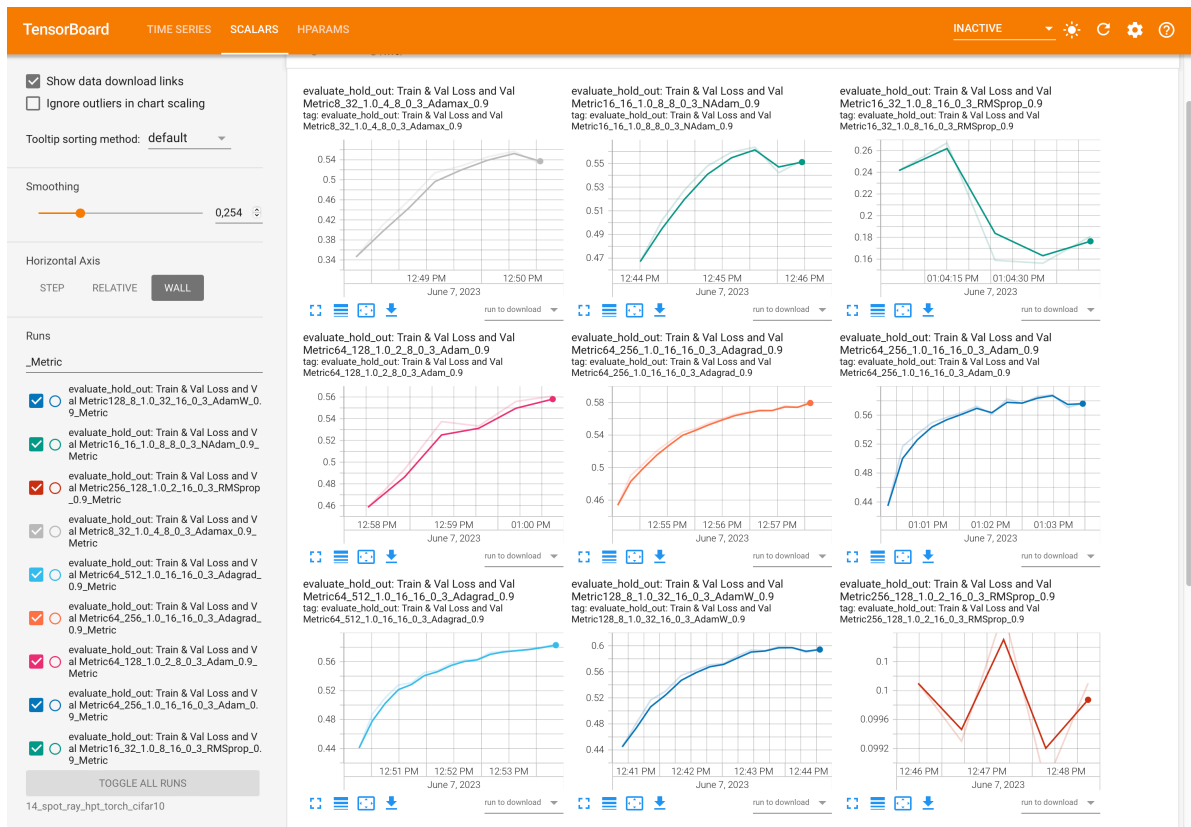


Figure 12.1: Tensorboard

TensorBoard									
INACTIVE									
TABLE VIEW									
Trial ID	Show Metrics	I1	I2	batch_size	epochs	patience	optimizer	fun_torch: loss	
1686135261.24...	<input type="checkbox"/>	64.000	512.00	16.000	16.000	3.0000	Adagrad	1.1765	
1686135486.0...	<input type="checkbox"/>	64.000	256.00	16.000	16.000	3.0000	Adagrad	1.1963	
1686134673.15...	<input type="checkbox"/>	128.00	8.0000	32.000	16.000	3.0000	AdamW	1.2062	
1686134773.50...	<input type="checkbox"/>	16.000	16.000	8.0000	8.0000	3.0000	NAdam	1.2880	
1686135837.96...	<input type="checkbox"/>	64.000	256.00	16.000	16.000	3.0000	Adam	1.3155	
1686135032.11...	<input type="checkbox"/>	8.0000	32.000	4.0000	8.0000	3.0000	Adamax	1.3435	
1686135637.40...	<input type="checkbox"/>	64.000	128.00	2.0000	8.0000	3.0000	Adam	1.5804	
1686135892.6...	<input type="checkbox"/>	16.000	32.000	8.0000	16.000	3.0000	RMSprop	2.1542	
1686134917.07...	<input type="checkbox"/>	256.00	128.00	2.0000	16.000	3.0000	RMSprop	2.3099	

Figure 12.2: Tensorboard


```
with open(result_file_name, 'rb') as f:
    spot_tuner = pickle.load(f)
```

12.10 Step 10: Results

After the hyperparameter tuning run is finished, the progress of the hyperparameter tuning can be visualized. The following code generates the progress plot from `?@fig-progress`.

```
spot_tuner.plot_progress(log_y=False,
    filename="./figures/" + experiment_name+"_progress.png")
```

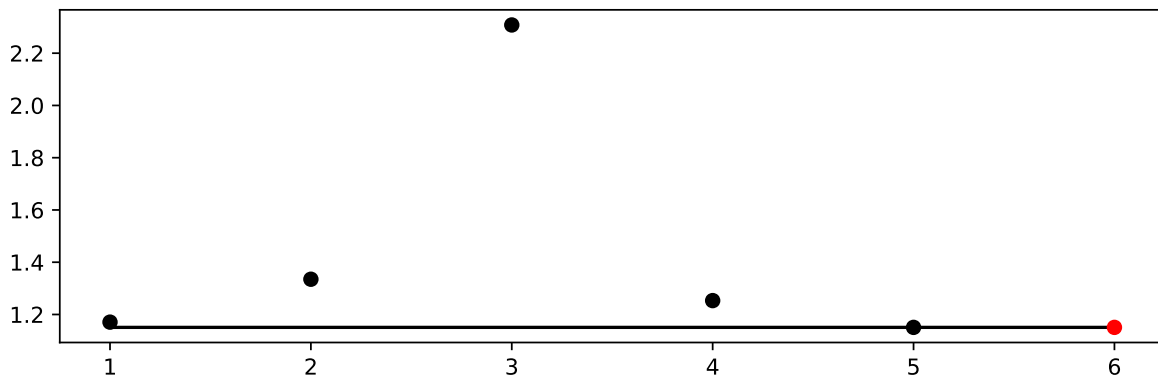


Figure 12.3: Progress plot. *Black* dots denote results from the initial design. *Red* dots illustrate the improvement found by the surrogate model based optimization.

`?@fig-progress` shows a typical behaviour that can be observed in many hyperparameter studies (Bartz et al. 2022): the largest improvement is obtained during the evaluation of the initial design. The surrogate model based optimization refines the results. `?@fig-progress` also illustrates one major difference between `ray[tune]` as used in PyTorch (2023a) and `spotPython`: the `ray[tune]` uses a random search and will generate results similar to the *black* dots, whereas `spotPython` uses a surrogate model based optimization and presents results represented by *red* dots in `?@fig-progress`. The surrogate model based optimization is considered to be more efficient than a random search, because the surrogate model guides the search towards promising regions in the hyperparameter space.

In addition to the improved (“optimized”) hyperparameter values, `spotPython` allows a statistical analysis, e.g., a sensitivity analysis, of the results. We can print the results of the hyperparameter tuning, see `?@tbl-results`. The table shows the hyperparameters, their types, default values, lower and upper bounds, and the transformation function. The column “tuned” shows

the tuned values. The column “importance” shows the importance of the hyperparameters. The column “stars” shows the importance of the hyperparameters in stars. The importance is computed by the SPOT software.

```
from spotPython.utils.eda import gen_design_table
print(gen_design_table(fun_control=fun_control, spot=spot_tuner))
```

name	type	default	lower	upper	tuned	transform
l1	int	5	2.0	9.0	6.0	transform_power_2_int
l2	int	5	2.0	9.0	9.0	transform_power_2_int
lr_mult	float	1.0	1.0	1.0	1.0	None
batch_size	int	4	1.0	5.0	4.0	transform_power_2_int
epochs	int	3	3.0	4.0	4.0	transform_power_2_int
k_folds	int	1	0.0	0.0	0.0	None
patience	int	5	3.0	3.0	3.0	None
optimizer	factor	SGD	0.0	9.0	1.0	None
sgd_momentum	float	0.0	0.9	0.9	0.9	None

To visualize the most important hyperparameters, `spotPython` provides the function `plot_importance`. The following code generates the importance plot from `?@fig-importance`.

```
spot_tuner.plot_importance(threshold=0.025,
                           filename="./figures/" + experiment_name+"_importance.png")
```

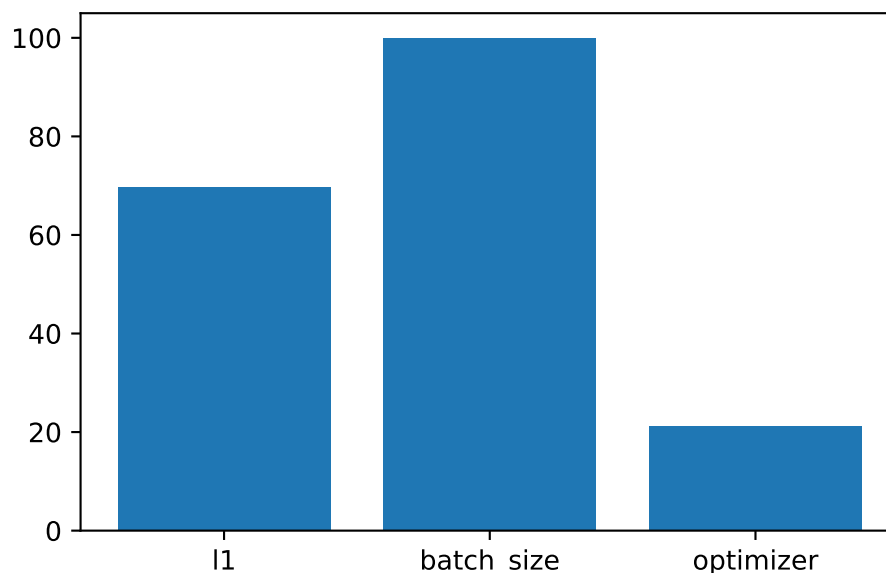


Figure 12.4: Variable importance plot, threshold 0.025.

12.10.1 Get the Tuned Architecture (SPOT Results)

The architecture of the `spotPython` model can be obtained as follows. First, the numerical representation of the hyperparameters are obtained, i.e., the numpy array `X` is generated. This array is then used to generate the model `model_spot` by the function `get_one_core_model_from_X`. The model `model_spot` has the following architecture:

```
from spotPython.hyperparameters.values import get_one_core_model_from_X
X = spot_tuner.to_all_dim(spot_tuner.min_X.reshape(1,-1))
model_spot = get_one_core_model_from_X(X, fun_control)
model_spot
```

```
Net_CIFAR10(
  (conv1): Conv2d(3, 6, kernel_size=(5, 5), stride=(1, 1))
  (pool): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (conv2): Conv2d(6, 16, kernel_size=(5, 5), stride=(1, 1))
  (fc1): Linear(in_features=400, out_features=64, bias=True)
  (fc2): Linear(in_features=64, out_features=512, bias=True)
  (fc3): Linear(in_features=512, out_features=10, bias=True)
)
```

12.10.2 Get Default Hyperparameters

In a similar manner as in Section 12.10.1, the default hyperparameters can be obtained.

```
# fun_control was modified, we generate a new one with the original
# default hyperparameters
from spotPython.hyperparameters.values import get_one_core_model_from_X
from spotPython.hyperparameters.values import get_default_hyperparameters_as_array
X_start = get_default_hyperparameters_as_array(fun_control)
model_default = get_one_core_model_from_X(X_start, fun_control)
model_default
```

```
Net_CIFAR10(
    (conv1): Conv2d(3, 6, kernel_size=(5, 5), stride=(1, 1))
    (pool): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    (conv2): Conv2d(6, 16, kernel_size=(5, 5), stride=(1, 1))
    (fc1): Linear(in_features=400, out_features=32, bias=True)
    (fc2): Linear(in_features=32, out_features=32, bias=True)
    (fc3): Linear(in_features=32, out_features=10, bias=True)
)
```

12.10.3 Evaluation of the Default Architecture

The method `train_tuned` takes a model architecture without trained weights and trains this model with the train data. The train data is split into train and validation data. The validation data is used for early stopping. The trained model weights are saved as a dictionary.

This evaluation is similar to the final evaluation in PyTorch (2023a).

```
from spotPython.torch.traintest import (
    train_tuned,
    test_tuned,
)
train_tuned(net=model_default, train_dataset=train, shuffle=True,
            loss_function=fun_control["loss_function"],
            metric=fun_control["metric_torch"],
            device = fun_control["device"], show_batch_interval=1_000_000,
            path=None,
            task=fun_control["task"],)

test_tuned(net=model_default, test_dataset=test,
```

```

    loss_function=fun_control["loss_function"],
    metric=fun_control["metric_torch"],
    shuffle=False,
    device = fun_control["device"],
    task=fun_control["task"],)

```

Epoch: 1 |

MulticlassAccuracy: 0.1013000011444092 | Loss: 2.2993141445159910 | Acc: 0.1013000000000000.

Epoch: 2 |

MulticlassAccuracy: 0.1157499998807907 | Loss: 2.2862340703964232 | Acc: 0.1157500000000000.

Epoch: 3 |

MulticlassAccuracy: 0.1534000039100647 | Loss: 2.2558290372848511 | Acc: 0.1534000000000000.

Epoch: 4 |

MulticlassAccuracy: 0.2099999934434891 | Loss: 2.2096890264511106 | Acc: 0.2100000000000000.

Epoch: 5 |

MulticlassAccuracy: 0.2170500010251999 | Loss: 2.1583908937454224 | Acc: 0.2170500000000000.

Epoch: 6 |

MulticlassAccuracy: 0.2304999977350235 | Loss: 2.1003360460281373 | Acc: 0.2305000000000000.

Epoch: 7 |

MulticlassAccuracy: 0.2407499998807907 | Loss: 2.0469172566413878 | Acc: 0.2407500000000000.

Epoch: 8 |

MulticlassAccuracy: 0.2523500025272369 | Loss: 2.0065287119865416 | Acc: 0.2523500000000000.

Returned to Spot: Validation loss: 2.0065287119865416

MulticlassAccuracy: 0.2574999928474426 | Loss: 2.0048587881088258 | Acc: 0.2575000000000000.

Final evaluation: Validation loss: 2.004858788108826

Final evaluation: Validation metric: 0.2574999928474426

(2.004858788108826, nan, tensor(0.2575, device='mps:0'))

12.10.4 Evaluation of the Tuned Architecture

The following code trains the model `model_spot`.

If `path` is set to a filename, e.g., `path = "model_spot_trained.pt"`, the weights of the trained model will be saved to this file.

If `path` is set to a filename, e.g., `path = "model_spot_trained.pt"`, the weights of the trained model will be loaded from this file.

```
train_tuned(net=model_spot, train_dataset=train,
            loss_function=fun_control["loss_function"],
            metric=fun_control["metric_torch"],
            shuffle=True,
            device = fun_control["device"],
            path=None,
            task=fun_control["task"],)
test_tuned(net=model_spot, test_dataset=test,
            shuffle=False,
            loss_function=fun_control["loss_function"],
            metric=fun_control["metric_torch"],
            device = fun_control["device"],
            task=fun_control["task"],)
```

Epoch: 1 |

MulticlassAccuracy: 0.4534499943256378 | Loss: 1.4870731952190399 | Acc: 0.4534500000000000.
Epoch: 2 |

MulticlassAccuracy: 0.4928500056266785 | Loss: 1.3916886319160462 | Acc: 0.4928500000000000.
Epoch: 3 |

MulticlassAccuracy: 0.5167000293731689 | Loss: 1.3368550091743470 | Acc: 0.5167000000000000.
Epoch: 4 |

MulticlassAccuracy: 0.5303000211715698 | Loss: 1.3082772194862367 | Acc: 0.5303000000000000.
Epoch: 5 |

MulticlassAccuracy: 0.5405499935150146 | Loss: 1.2846001376152039 | Acc: 0.5405500000000000.
Epoch: 6 |

MulticlassAccuracy: 0.5463500022888184 | Loss: 1.2691698253631591 | Acc: 0.5463500000000000.
Epoch: 7 |

MulticlassAccuracy: 0.5541499853134155 | Loss: 1.2507742740154266 | Acc: 0.5541500000000000.
Epoch: 8 |

MulticlassAccuracy: 0.5570499897003174 | Loss: 1.2399426158189772 | Acc: 0.5570500000000000.
Epoch: 9 |

MulticlassAccuracy: 0.5670499801635742 | Loss: 1.2221989663839341 | Acc: 0.5670500000000001.
Epoch: 10 |

MulticlassAccuracy: 0.5644500255584717 | Loss: 1.2227670684814453 | Acc: 0.5644500000000000.
Epoch: 11 |

MulticlassAccuracy: 0.5721499919891357 | Loss: 1.2138653992414474 | Acc: 0.5721500000000000.
Epoch: 12 |

MulticlassAccuracy: 0.5729500055313110 | Loss: 1.2096151790142060 | Acc: 0.5729500000000000.
Epoch: 13 |

MulticlassAccuracy: 0.5751500129699707 | Loss: 1.1991128283262253 | Acc: 0.5751500000000001.
Epoch: 14 |

MulticlassAccuracy: 0.5822499990463257 | Loss: 1.1887103311300278 | Acc: 0.5822500000000000.
Epoch: 15 |

MulticlassAccuracy: 0.5832499861717224 | Loss: 1.1874288388013841 | Acc: 0.5832500000000000.
Epoch: 16 |

MulticlassAccuracy: 0.5831500291824341 | Loss: 1.1802469824314117 | Acc: 0.5831499999999999.
Returned to Spot: Validation loss: 1.1802469824314117

MulticlassAccuracy: 0.5817000269889832 | Loss: 1.1879083695888519 | Acc: 0.5817000000000000.
Final evaluation: Validation loss: 1.187908369588852
Final evaluation: Validation metric: 0.5817000269889832

(1.187908369588852, nan, tensor(0.5817, device='mps:0'))

12.10.5 Detailed Hyperparameter Plots

The contour plots in this section visualize the interactions of the three most important hyperparameters. Since some of these hyperparameters take factorial or integer values, sometimes step-like fitness landscapes (or response surfaces) are generated. SPOT draws the interactions of the main hyperparameters by default. It is also possible to visualize all interactions.

```
filename = "./figures/" + experiment_name
spot_tuner.plot_important_hyperparameter_contour(filename=filename)
```

```
l1: 69.75840235467982
batch_size: 100.0
optimizer: 21.10469769869686
```

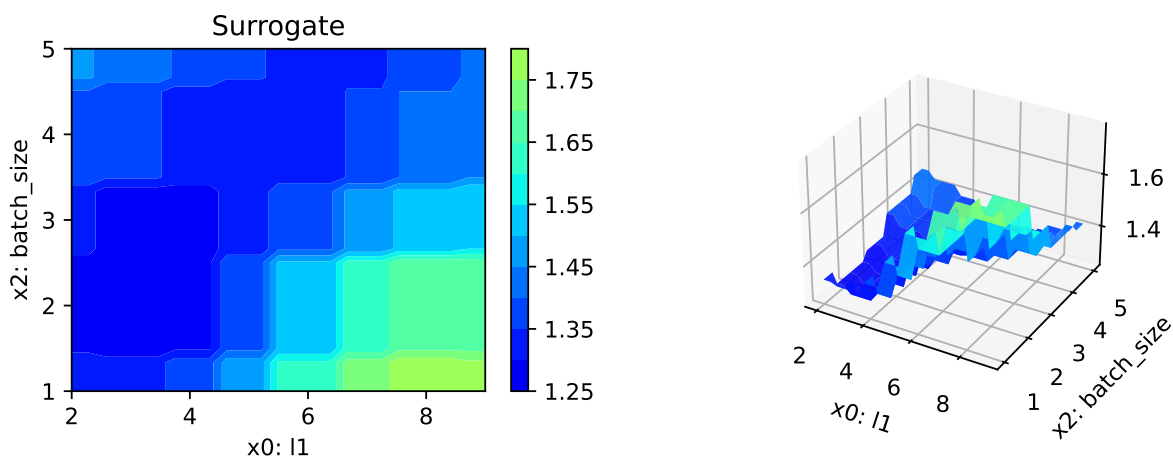
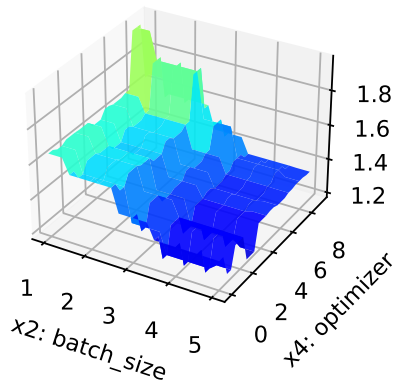
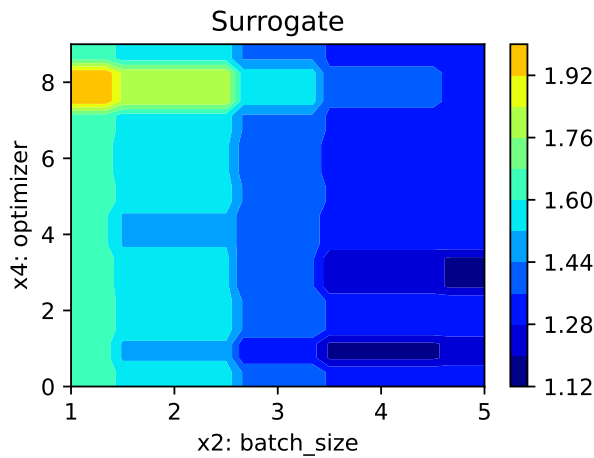
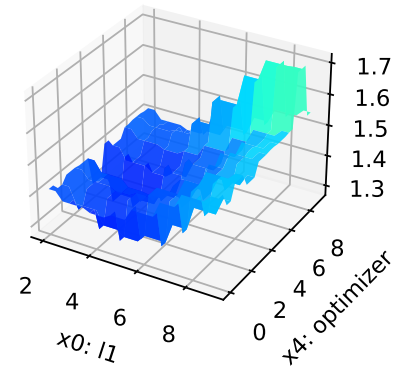
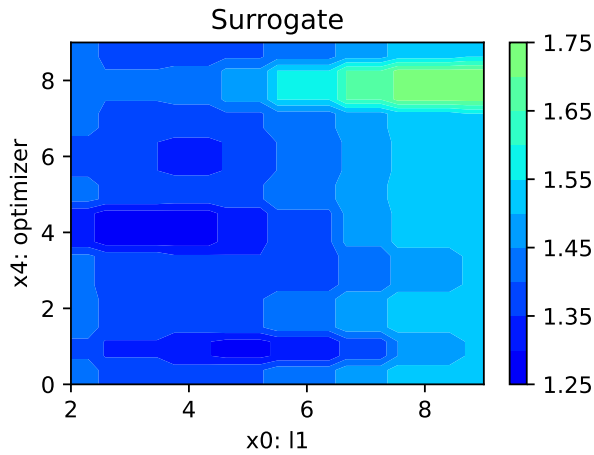


Figure 12.5: Contour plots.



The figures ([?@fig-contour](#)) show the contour plots of the loss as a function of the hyperparameters. These plots are very helpful for benchmark studies and for understanding neural networks. `spotPython` provides additional tools for a visual inspection of the results and give valuable insights into the hyperparameter tuning process. This is especially useful for model explainability, transparency, and trustworthiness. In addition to the contour plots, [?@fig-parallel](#) shows the parallel plot of the hyperparameters.

```
spot_tuner.parallel_plot()
```

Unable to display output for mime type(s): text/html

Parallel coordinates plots

Unable to display output for mime type(s): text/html

12.11 Summary and Outlook

This tutorial presents the hyperparameter tuning open source software `spotPython` for `PyTorch`. To show its basic features, a comparison with the “official” `PyTorch` hyperparameter tuning tutorial (PyTorch 2023a) is presented. Some of the advantages of `spotPython` are:

- Numerical and categorical hyperparameters.
- Powerful surrogate models.
- Flexible approach and easy to use.
- Simple JSON files for the specification of the hyperparameters.
- Extension of default and user specified network classes.
- Noise handling techniques.
- Interaction with `tensorboard`.

Currently, only rudimentary parallel and distributed neural network training is possible, but these capabilities will be extended in the future. The next version of `spotPython` will also include a more detailed documentation and more examples.

! Important

Important: This tutorial does not present a complete benchmarking study (Bartz-Beielstein et al. 2020). The results are only preliminary and highly dependent on the local configuration (hard- and software). Our goal is to provide a first impression of the performance of the hyperparameter tuning package `spotPython`. To demonstrate its capabilities, a quick comparison with `ray[tune]` was performed. `ray[tune]` was chosen, because it is presented as “an industry standard tool for distributed hyperparameter tuning.” The results should be interpreted with care.

12.12 Appendix

12.12.1 Sample Output From Ray Tune’s Run

The output from `ray[tune]` could look like this (PyTorch 2023b):

```
Number of trials: 10 (10 TERMINATED)
-----+-----+-----+-----+-----+-----+-----+
|  11  |  12  |           lr |  batch_size |    loss |  accuracy | training_iteration |
```


13 HPT: sklearn RandomForestClassifier VBDP Data

spotPython can be installed via pip. Alternatively, the source code can be downloaded from gitHub: <https://github.com/sequential-parameter-optimization/spotPython>.

```
!pip install spotPython
```

- Uncomment the following lines if you want to for (re-)installation the latest version of spotPython from gitHub.

```
# import sys
# !{sys.executable} -m pip install --upgrade build
# !{sys.executable} -m pip install --upgrade --force-reinstall spotPython
```

13.1 Step 1: Setup

Before we consider the detailed experimental setup, we select the parameters that affect run time and the initial design size.

```
MAX_TIME = 1
INIT_SIZE = 5
ORIGINAL = False
PREFIX = "16"
```

```
import warnings
warnings.filterwarnings("ignore")
```

13.2 Step 2: Initialization of the Empty fun_control Dictionary

```
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_experiment_name, get_spot_tensorboard_path
from spotPython.utils.device import getDevice

experiment_name = get_experiment_name(prefix=PREFIX)

fun_control = fun_control_init(
    task="classification",
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name))
```

13.3 Step 3: PyTorch Data Loading

13.3.1 Load Data: Classification VBDP

```
import pandas as pd
if ORIGINAL == True:
    train_df = pd.read_csv('./data/VBDP/trainnn.csv')
    test_df = pd.read_csv('./data/VBDP/testtt.csv')
else:
    train_df = pd.read_csv('./data/VBDP/train.csv')
    # remove the id column
    train_df = train_df.drop(columns=['id'])

from sklearn.preprocessing import OrdinalEncoder
n_samples = train_df.shape[0]
n_features = train_df.shape[1] - 1
target_column = "prognosis"
# Encoder our prognosis labels as integers for easier decoding later
enc = OrdinalEncoder()
train_df[target_column] = enc.fit_transform(train_df[[target_column]])
train_df.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
print(train_df.shape)
train_df.head()
```

(707, 65)

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19
0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	1.0
1	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0
2	0.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0
3	0.0	0.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	1.0	1.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The full data set `train_df` 64 features. The target column is labeled as `prognosis`.

13.3.2 Holdout Train and Test Data

We split out a hold-out test set (25% of the data) so we can calculate an example MAP@K

```
import numpy as np
from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = train_test_split(train_df.drop(target_column, axis=1),
                                                    random_state=42,
                                                    test_size=0.25,
                                                    stratify=train_df[target_column])
train = pd.DataFrame(np.hstack((X_train, np.array(y_train).reshape(-1, 1))))
test = pd.DataFrame(np.hstack((X_test, np.array(y_test).reshape(-1, 1))))
train.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
test.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
print(train.shape)
print(test.shape)
train.head()
```

(530, 65)

(177, 65)

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19
0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0
2	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0
4	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0

```
# add the dataset to the fun_control
fun_control.update({"data": train_df, # full dataset,
                   "train": train,
```

```

        "test": test,
        "n_samples": n_samples,
        "target_column": target_column})

```

13.4 Step 4: Specification of the Preprocessing Model

Data preprocessing can be very simple, e.g., you can ignore it. Then you would choose the `prep_model` "None":

```

prep_model = None
fun_control.update({"prep_model": prep_model})

```

A default approach for numerical data is the `StandardScaler` (mean 0, variance 1). This can be selected as follows:

```

# prep_model = StandardScaler()
# fun_control.update({"prep_model": prep_model})

```

Even more complicated pre-processing steps are possible, e.g., the following pipeline:

```

# categorical_columns = []
# one_hot_encoder = OneHotEncoder(handle_unknown="ignore", sparse_output=False)
# prep_model = ColumnTransformer(
#     transformers=[
#         ("categorical", one_hot_encoder, categorical_columns),
#     ],
#     remainder=StandardScaler(),
# )

```

13.5 Step 5: Select Model (algorithm) and `core_model_hyper_dict`

The selection of the algorithm (ML model) that should be tuned is done by specifying the its name from the `sklearn` implementation. For example, the `SVC` support vector machine classifier is selected as follows:

```

add_core_model_to_fun_control(SVC, fun_control, SklearnHyperDict)

```

Other `core_models` are, e.g.,:

- RidgeCV
- GradientBoostingRegressor
- ElasticNet
- RandomForestClassifier
- LogisticRegression
- KNeighborsClassifier
- RandomForestClassifier
- GradientBoostingClassifier
- HistGradientBoostingClassifier

We will use the `RandomForestClassifier` classifier in this example.

```
from sklearn.linear_model import RidgeCV
from sklearn.ensemble import RandomForestClassifier
from sklearn.svm import SVC
from sklearn.linear_model import LogisticRegression
from sklearn.neighbors import KNeighborsClassifier
from sklearn.ensemble import GradientBoostingClassifier
from sklearn.ensemble import GradientBoostingRegressor
from sklearn.linear_model import ElasticNet
from spotPython.hyperparameters.values import add_core_model_to_fun_control
from spotPython.data.sklearn_hyper_dict import SklearnHyperDict
from spotPython.fun.hypersklearn import HyperSklearn

# core_model = RidgeCV
# core_model = GradientBoostingRegressor
# core_model = ElasticNet
core_model = RandomForestClassifier
# core_model = SVC
# core_model = LogisticRegression
# core_model = KNeighborsClassifier
# core_model = GradientBoostingClassifier
add_core_model_to_fun_control(core_model=core_model,
                             fun_control=fun_control,
                             hyper_dict=SklearnHyperDict,
                             filename=None)
```

Now `fun_control` has the information from the JSON file. The available hyperparameters are:

```
print(*fun_control["core_model_hyper_dict"].keys(), sep="\n")
```



```

n_estimators
criterion
max_depth
min_samples_split
min_samples_leaf
min_weight_fraction_leaf
max_features
max_leaf_nodes
min_impurity_decrease
bootstrap
oob_score

```

13.6 Step 6: Modify hyper_dict Hyperparameters for the Selected Algorithm aka core_model

13.6.1 Modify hyperparameter of type numeric and integer (boolean)

Numeric and boolean values can be modified using the `modify_hyper_parameter_bounds` method. For example, to change the `tol` hyperparameter of the `SVC` model to the interval `[1e-3, 1e-2]`, the following code can be used:

```

modify_hyper_parameter_bounds(fun_control, "tol", bounds=[1e-3, 1e-2])

from spotPython.hyperparameters.values import modify_hyper_parameter_bounds
# modify_hyper_parameter_bounds(fun_control, "tol", bounds=[1e-3, 1e-2])

```

13.6.2 Modify hyperparameter of type factor

`spotPython` provides functions for modifying the hyperparameters, their bounds and factors as well as for activating and de-activating hyperparameters without re-compilation of the Python source code. These functions were described in [Section 12.6](#).

Factors can be modified with the `modify_hyper_parameter_levels` function. For example, to exclude the `sigmoid` kernel from the tuning, the `kernel` hyperparameter of the `SVC` model can be modified as follows:

```

modify_hyper_parameter_levels(fun_control, "kernel", ["linear", "rbf"])

```

The new setting can be controlled via:

```

fun_control["core_model_hyper_dict"]["kernel"]

```

```
from spotPython.hyperparameters.values import modify_hyper_parameter_levels
# XGBoost:
# modify_hyper_parameter_levels(fun_control, "loss", ["log_loss"])
```

i Note: RandomForestClassifier and Out-of-bag Estimation

Since `oob_score` requires the `bootstrap` hyperparameter to `True`, we set the `oob_score` parameter to `False`. The `oob_score` is later discussed in Section 13.7.3.

```
modify_hyper_parameter_bounds(fun_control, "bootstrap", bounds=[0, 1])
modify_hyper_parameter_bounds(fun_control, "oob_score", bounds=[0, 0])
```

13.6.3 Optimizers

Optimizers are described in Section 12.6.1.

13.6.4 Selection of the Objective: Metric and Loss Functions

- Machine learning models are optimized with respect to a metric, for example, the accuracy function.
- Deep learning, e.g., neural networks are optimized with respect to a loss function, for example, the `cross_entropy` function and evaluated with respect to a metric, for example, the accuracy function.

13.7 Step 7: Selection of the Objective (Loss) Function

The loss function, that is usually used in deep learning for optimizing the weights of the net, is stored in the `fun_control` dictionary as `"loss_function"`.

13.7.1 Metric Function

There are two different types of metrics in `spotPython`:

1. `"metric_river"` is used for the river based evaluation via `eval_oml_iter_progressive`.
2. `"metric_sklearn"` is used for the sklearn based evaluation.

We will consider multi-class classification metrics, e.g., `mapk_score` and `top_k_accuracy_score`.

i Predict Probabilities

In this multi-class classification example the machine learning algorithm should return the probabilities of the specific classes ("**predict_proba**") instead of the predicted values.

We set "**predict_proba**" to **True** in the **fun_control** dictionary.

13.7.1.1 The MAPK Metric

To select the MAPK metric, the following two entries can be added to the **fun_control** dictionary:

```
"metric_sklearn": mapk_score"  
"metric_params": {"k": 3}.
```

13.7.1.2 Other Metrics

Alternatively, other metrics for multi-class classification can be used, e.g., * **top_k_accuracy_score** or * **roc_auc_score**

The metric **roc_auc_score** requires the parameter "**multi_class**", e.g.,

```
"multi_class": "ovr".
```

This is set in the **fun_control** dictionary.

i Weights

spotPython performs a minimization, therefore, metrics that should be maximized have to be multiplied by -1. This is done by setting "**weights**" to -1.

- The complete setup for the metric in our example is:

```
from spotPython.utils.metrics import mapk_score  
fun_control.update({  
    "weights": -1,  
    "metric_sklearn": mapk_score,  
    "predict_proba": True,  
    "metric_params": {"k": 3},  
})
```

13.7.2 Evaluation on Hold-out Data

- The default method for computing the performance is "eval_holdout".
- Alternatively, cross-validation can be used for every machine learning model.
- Specifically for RandomForests, the OOB-score can be used.

```
fun_control.update({
    "eval": "train_hold_out",
})
```

13.7.3 OOB Score

Using the OOB-Score is a very efficient way to estimate the performance of a random forest classifier. The OOB-Score is calculated on the training data and does not require a hold-out test set. If the OOB-Score is used, the key "eval" in the `fun_control` dictionary should be set to "oob_score" as shown below.

OOB-Score

In addition to setting the key "eval" in the `fun_control` dictionary to "oob_score", the keys "oob_score" and "bootstrap" have to be set to True, because the OOB-Score requires the bootstrap method.

- Uncomment the following lines to use the OOB-Score:

```
fun_control.update({
    "eval": "eval_oob_score",
})
modify_hyper_parameter_bounds(fun_control, "bootstrap", bounds=[1, 1])
modify_hyper_parameter_bounds(fun_control, "oob_score", bounds=[1, 1])
```

13.7.3.1 Cross Validation

Instead of using the OOB-score, the classical cross validation can be used. The number of folds is set by the key "k_folds". For example, to use 5-fold cross validation, the key "k_folds" is set to 5. Uncomment the following line to use cross validation:

```
# fun_control.update({
#     "eval": "train_cv",
#     "k_folds": 10,
```

```
# })
```

13.8 Step 8: Calling the SPOT Function

13.8.1 Preparing the SPOT Call

- Get types and variable names as well as lower and upper bounds for the hyperparameters.

```
# extract the variable types, names, and bounds
from spotPython.hyperparameters.values import (get_bound_values,
        get_var_name,
        get_var_type,)
var_type = get_var_type(fun_control)
var_name = get_var_name(fun_control)
lower = get_bound_values(fun_control, "lower")
upper = get_bound_values(fun_control, "upper")
```

```
from spotPython.utils.eda import gen_design_table
print(gen_design_table(fun_control))
```

name	type	default	lower	upper	transform
n_estimators	int	7	5	10	transform_power_2_int
criterion	factor	gini	0	2	None
max_depth	int	10	1	20	transform_power_2_int
min_samples_split	int	2	2	100	None
min_samples_leaf	int	1	1	25	None
min_weight_fraction_leaf	float	0.0	0	0.01	None
max_features	factor	sqrt	0	1	transform_none_to_None
max_leaf_nodes	int	10	7	12	transform_power_2_int
min_impurity_decrease	float	0.0	0	0.01	None
bootstrap	factor	1	1	1	None
oob_score	factor	0	1	1	None

13.8.2 The Objective Function

The objective function is selected next. It implements an interface from `sklearn`'s training, validation, and testing methods to `spotPython`.

```
from spotPython.fun.hypersklearn import HyperSklearn
fun = HyperSklearn().fun_sklearn
```

13.8.3 Run the Spot Optimizer

- Run SPOT for approx. x mins (max_time).
- Note: the run takes longer, because the evaluation time of initial design (here: initi_size, 20 points) is not considered.

```
from spotPython.hyperparameters.values import get_default_hyperparameters_as_array
X_start = get_default_hyperparameters_as_array(fun_control)
X_start
```

```
array([[ 7.,  0., 10.,  2.,  1.,  0.,  0., 10.,  0.,  1.,  0.]])
```

```
import numpy as np
from spotPython.spot import spot
from math import inf
spot_tuner = spot.Spot(fun=fun,
                      lower = lower,
                      upper = upper,
                      fun_evals = inf,
                      fun_repeats = 1,
                      max_time = MAX_TIME,
                      noise = False,
                      tolerance_x = np.sqrt(np.spacing(1)),
                      var_type = var_type,
                      var_name = var_name,
                      infill_criterion = "y",
                      n_points = 1,
                      seed=123,
                      log_level = 50,
                      show_models= False,
                      show_progress= True,
                      fun_control = fun_control,
                      design_control={"init_size": INIT_SIZE,
                                     "repeats": 1},
                      surrogate_control={"noise": True,
                                       "cod_type": "norm",
                                       "min_theta": -4,
```

```

        "max_theta": 3,
        "n_theta": len(var_name),
        "model_fun_evals": 10_000,
        "log_level": 50
    })

spot_tuner.run(X_start=X_start)

```

```

spotPython tuning: -0.34276729559748426 [-----] 1.47%

spotPython tuning: -0.34685534591194966 [-----] 2.77%

spotPython tuning: -0.34685534591194966 [-----] 3.69%

spotPython tuning: -0.34685534591194966 [#-----] 5.12%

spotPython tuning: -0.34685534591194966 [#-----] 6.56%

spotPython tuning: -0.34685534591194966 [#-----] 8.04%

spotPython tuning: -0.34685534591194966 [#-----] 9.27%

spotPython tuning: -0.34685534591194966 [#-----] 10.50%

spotPython tuning: -0.34685534591194966 [#-----] 12.18%

spotPython tuning: -0.34685534591194966 [#-----] 14.27%

spotPython tuning: -0.34685534591194966 [##-----] 15.83%

spotPython tuning: -0.34685534591194966 [##-----] 17.31%

spotPython tuning: -0.34685534591194966 [##-----] 20.15%

spotPython tuning: -0.34685534591194966 [###-----] 25.91%

spotPython tuning: -0.34685534591194966 [###-----] 31.43%

```

```

spotPython tuning: -0.34685534591194966 [####-----] 36.80%
spotPython tuning: -0.34685534591194966 [####-----] 39.84%
spotPython tuning: -0.34874213836477985 [#####-----] 45.28%
spotPython tuning: -0.35188679245283017 [#####-----] 49.31%
spotPython tuning: -0.35188679245283017 [#####-----] 54.67%
spotPython tuning: -0.3534591194968553 [#####-----] 60.28%
spotPython tuning: -0.3581761006289308 [#####----] 65.95%
spotPython tuning: -0.3581761006289308 [#####----] 70.88%
spotPython tuning: -0.3581761006289308 [#####---] 75.02%
spotPython tuning: -0.3581761006289308 [#####---] 81.96%
spotPython tuning: -0.3581761006289308 [#####--] 86.27%
spotPython tuning: -0.3581761006289308 [#####--] 92.27%
spotPython tuning: -0.3581761006289308 [#####] 98.34%
spotPython tuning: -0.36163522012578614 [#####] 100.00% Done...

<spotPython.spot.spot.Spot at 0x2cce57910>

```

13.9 Step 9: Tensorboard

The textual output shown in the console (or code cell) can be visualized with Tensorboard as described in Section 12.9, see also the description in the documentation: [Tensorboard](#).

13.10 Step 10: Results

After the hyperparameter tuning run is finished, the progress of the hyperparameter tuning can be visualized. The following code generates the progress plot from `?@fig-progress`.


```
spot_tuner.plot_progress(log_y=False,
                        filename="./figures/" + experiment_name+"_progress.png")
```

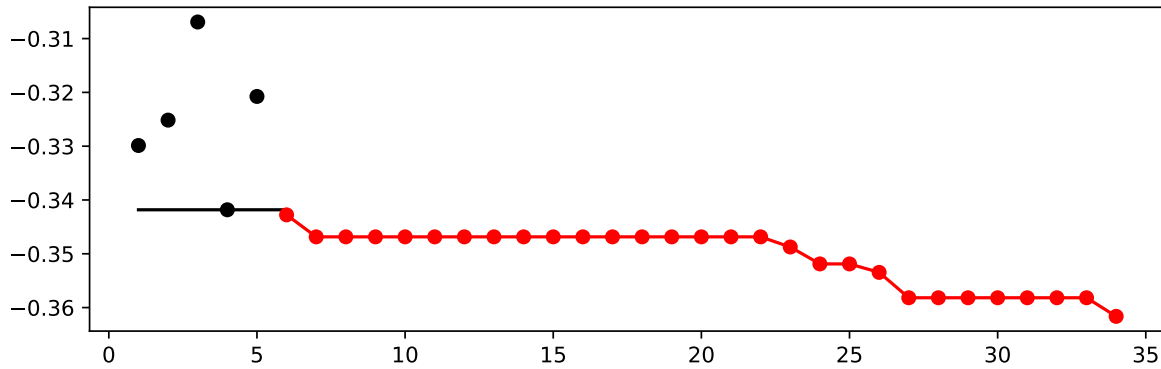


Figure 13.1: Progress plot. *Black* dots denote results from the initial design. *Red* dots illustrate the improvement found by the surrogate model based optimization.

- Print the results

```
print(gen_design_table(fun_control=fun_control,
                      spot=spot_tuner))
```

name	type	default	lower	upper	tuned
n_estimators	int	7	5.0	10.0	10.0
criterion	factor	gini	0.0	2.0	1.0
max_depth	int	10	1.0	20.0	10.0
min_samples_split	int	2	2.0	100.0	2.0
min_samples_leaf	int	1	1.0	25.0	1.0
min_weight_fraction_leaf	float	0.0	0.0	0.01	0.008341673749104165
max_features	factor	sqrt	0.0	1.0	0.0
max_leaf_nodes	int	10	7.0	12.0	9.0
min_impurity_decrease	float	0.0	0.0	0.01	0.01
bootstrap	factor	1	1.0	1.0	1.0
oob_score	factor	0	1.0	1.0	1.0

13.10.1 Show variable importance

```
spot_tuner.plot_importance(threshold=0.025, filename="./figures/" + experiment_name+"_impo
```

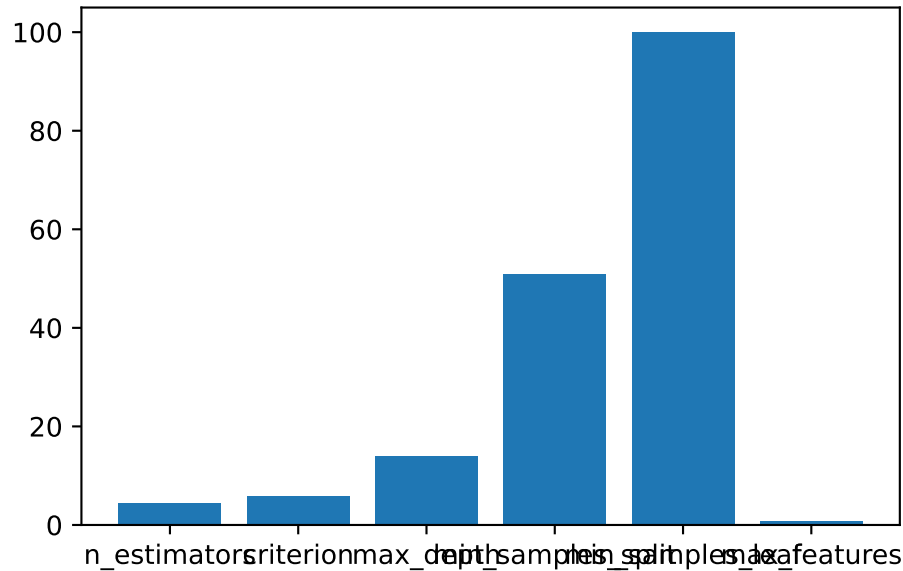


Figure 13.2: Variable importance plot, threshold 0.025.

13.10.2 Get Default Hyperparameters

```
from spotPython.hyperparameters.values import get_default_values, transform_hyper_parameter_values_default = get_default_values(fun_control) values_default = transform_hyper_parameter_values(fun_control=fun_control, hyper_parameter_values_default
```

```
{'n_estimators': 128,
 'criterion': 'gini',
 'max_depth': 1024,
 'min_samples_split': 2,
 'min_samples_leaf': 1,
 'min_weight_fraction_leaf': 0.0,
 'max_features': 'sqrt',
 'max_leaf_nodes': 1024,
 'min_impurity_decrease': 0.0,
```

```
'bootstrap': 1,
'ooob_score': 0}
```

```
from sklearn.pipeline import make_pipeline
model_default = make_pipeline(fun_control["prep_model"], fun_control["core_model"](**value
model_default
```

```
Pipeline(steps=[('nonetype', None),
                  ('randomforestclassifier',
                   RandomForestClassifier(bootstrap=1, max_depth=1024,
                                         max_leaf_nodes=1024, n_estimators=128,
                                         oob_score=0))])
```

13.10.3 Get SPOT Results

```
X = spot_tuner.to_all_dim(spot_tuner.min_X.reshape(1,-1))
print(X)
```

```
[[1.00000000e+01 1.00000000e+00 1.00000000e+01 2.00000000e+00
 1.00000000e+00 8.34167375e-03 0.00000000e+00 9.00000000e+00
 1.00000000e-02 1.00000000e+00 1.00000000e+00]]
```

```
from spotPython.hyperparameters.values import assign_values, return_conf_list_from_var_dict
v_dict = assign_values(X, fun_control["var_name"])
return_conf_list_from_var_dict(var_dict=v_dict, fun_control=fun_control)
```

```
[{'n_estimators': 1024,
  'criterion': 'entropy',
  'max_depth': 1024,
  'min_samples_split': 2,
  'min_samples_leaf': 1,
  'min_weight_fraction_leaf': 0.008341673749104165,
  'max_features': 'sqrt',
  'max_leaf_nodes': 512,
  'min_impurity_decrease': 0.01,
  'bootstrap': 1,
  'oob_score': 1}]
```

```

from spotPython.hyperparameters.values import get_one_sklearn_model_from_X
model_spot = get_one_sklearn_model_from_X(X, fun_control)
model_spot

```

```

RandomForestClassifier(bootstrap=1, criterion='entropy', max_depth=1024,
                        max_leaf_nodes=512, min_impurity_decrease=0.01,
                        min_weight_fraction_leaf=0.008341673749104165,
                        n_estimators=1024, oob_score=1)

```

13.10.4 Evaluate SPOT Results

- Fetch the data.

```

from spotPython.utils.convert import get_Xy_from_df
X_train, y_train = get_Xy_from_df(fun_control["train"], fun_control["target_column"])
X_test, y_test = get_Xy_from_df(fun_control["test"], fun_control["target_column"])
X_test.shape, y_test.shape

```

```
((177, 64), (177,))
```

- Fit the model with the tuned hyperparameters. This gives one result:

```

model_spot.fit(X_train, y_train)
y_pred = model_spot.predict_proba(X_test)
res = mapk_score(y_true=y_test, y_pred=y_pred, k=3)
res

```

```
0.3465160075329567
```

```

def repeated_eval(n, model):
    res_values = []
    for i in range(n):
        model.fit(X_train, y_train)
        y_pred = model.predict_proba(X_test)
        res = mapk_score(y_true=y_test, y_pred=y_pred, k=3)
        res_values.append(res)
    mean_res = np.mean(res_values)
    print(f"mean_res: {mean_res}")
    std_res = np.std(res_values)

```

```

print(f"std_res: {std_res}")
min_res = np.min(res_values)
print(f"min_res: {min_res}")
max_res = np.max(res_values)
print(f"max_res: {max_res}")
median_res = np.median(res_values)
print(f"median_res: {median_res}")
return mean_res, std_res, min_res, max_res, median_res

```

13.10.5 Handling Non-deterministic Results

- Because the model is non-deterministic, we perform $n = 30$ runs and calculate the mean and standard deviation of the performance metric.

```
_ = repeated_eval(30, model_spot)
```

```

mean_res: 0.3571876961707471
std_res: 0.006089463559461536
min_res: 0.34463276836158185
max_res: 0.36911487758945394
median_res: 0.35781544256120523

```

13.10.6 Evaluation of the Default Hyperparameters

```
model_default.fit(X_train, y_train)["randomforestclassifier"]
```

```

RandomForestClassifier(bootstrap=1, max_depth=1024, max_leaf_nodes=1024,
                        n_estimators=128, oob_score=0)

```

- One evaluation of the default hyperparameters is performed on the hold-out test set.

```

y_pred = model_default.predict_proba(X_test)
mapk_score(y_true=y_test, y_pred=y_pred, k=3)

```

```
0.3267419962335216
```

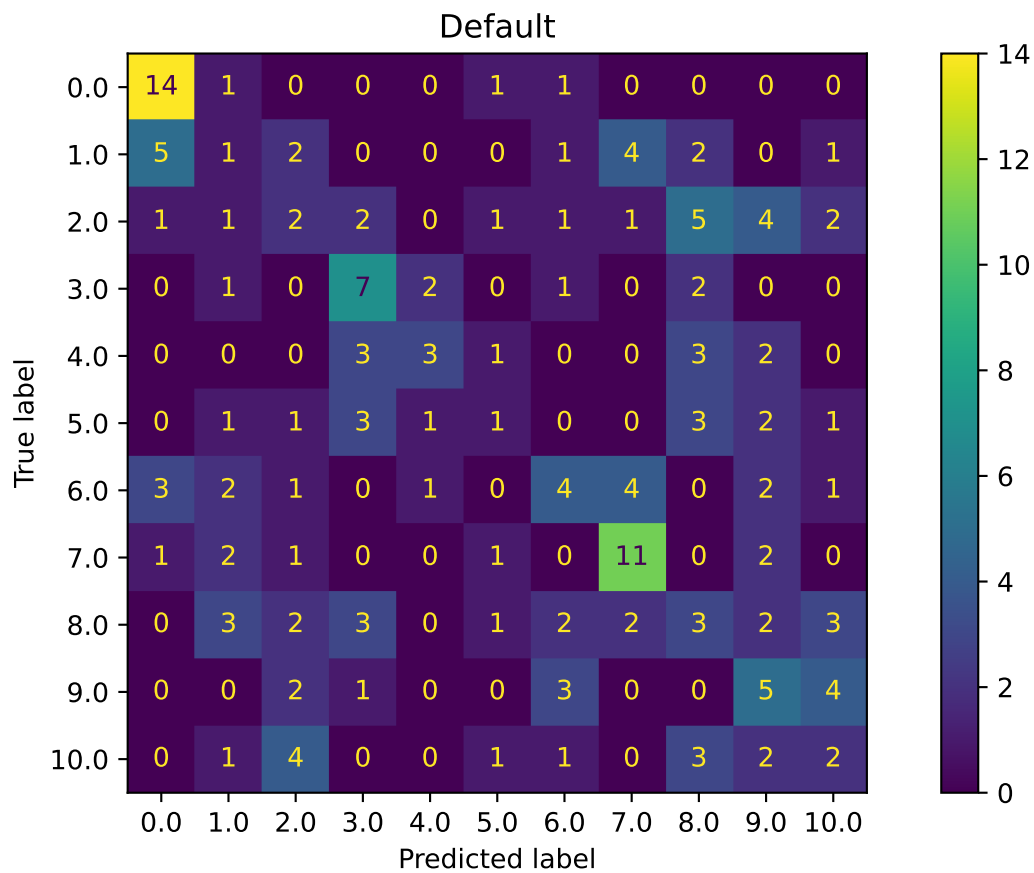
Since one single evaluation is not meaningful, we perform, similar to the evaluation of the SPOT results, $n = 30$ runs of the default setting and calculate the mean and standard deviation of the performance metric.

```
_ = repeated_eval(30, model_default)
```

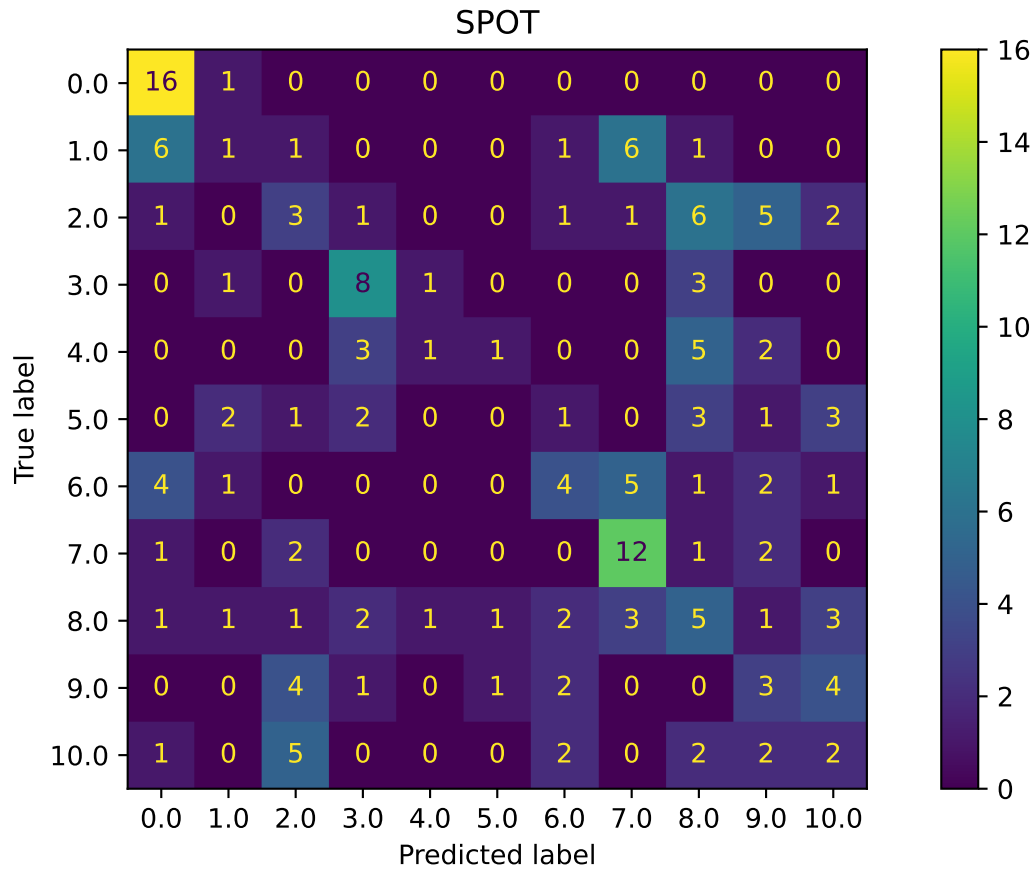
```
mean_res: 0.34202762084118
std_res: 0.014730019225568549
min_res: 0.3135593220338983
max_res: 0.3757062146892655
median_res: 0.3418079096045198
```

13.10.7 Plot: Compare Predictions

```
from spotPython.plot.validation import plot_confusion_matrix
plot_confusion_matrix(model_default, fun_control, title = "Default")
```



```
plot_confusion_matrix(model_spot, fun_control, title="SPOT")
```



```
min(spot_tuner.y), max(spot_tuner.y)
```

```
(-0.36163522012578614, -0.27578616352201263)
```

13.10.8 Cross-validated Evaluations

```
from spotPython.sklearn.traintest import evaluate_cv
fun_control.update({
    "eval": "train_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)
```

```
(0.3584905660377358, None)
```



```

fun_control.update({
    "eval": "test_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)

```

(0.3425381263616557, None)

- This is the evaluation that will be used in the comparison:

```

fun_control.update({
    "eval": "data_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)

```

(0.36150570087189804, None)

13.10.9 Detailed Hyperparameter Plots

```

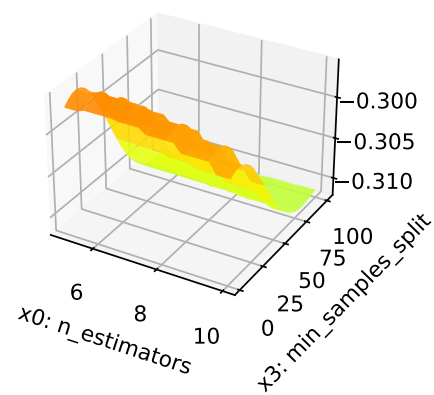
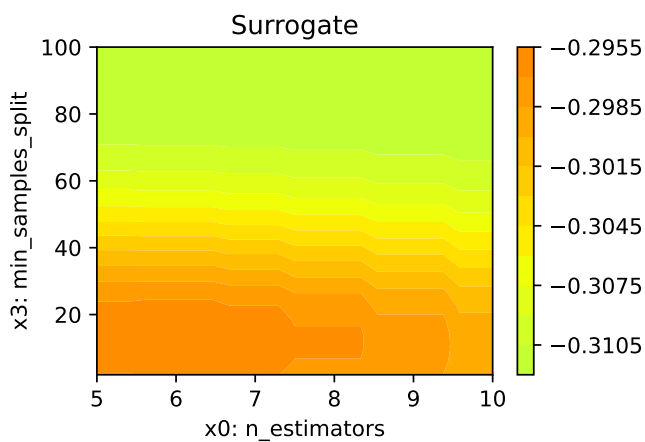
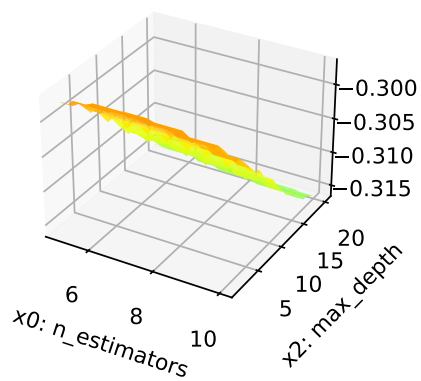
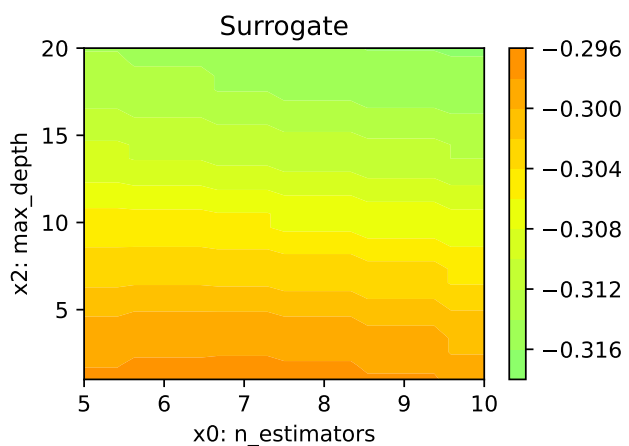
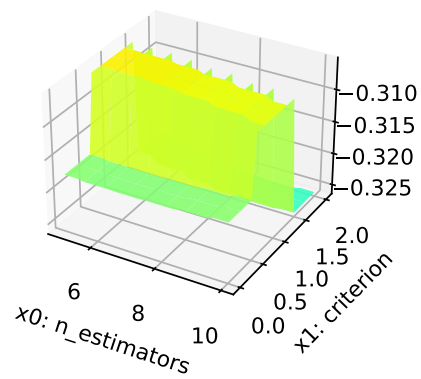
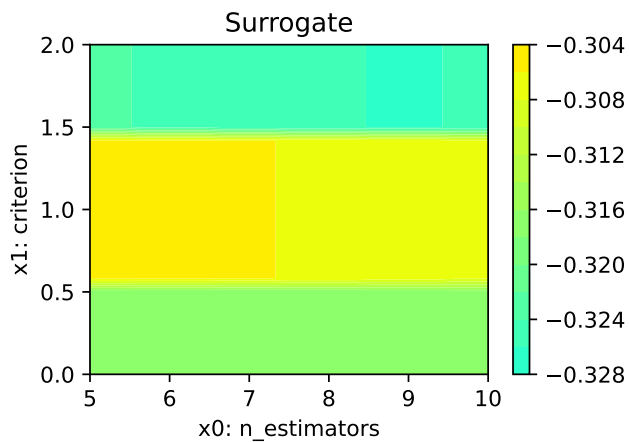
filename = "./figures/" + experiment_name
spot_tuner.plot_important_hyperparameter_contour(filename=filename)

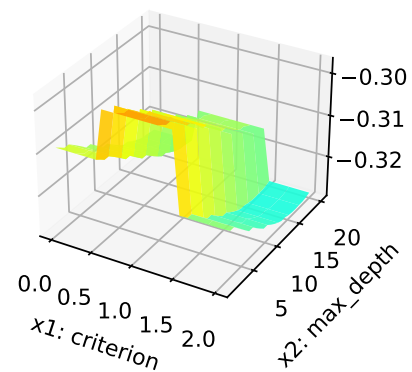
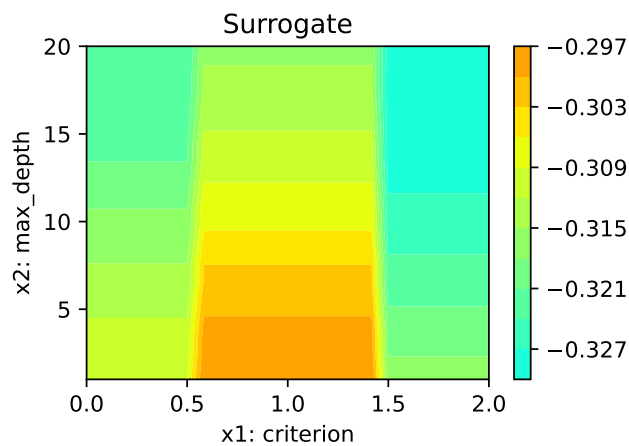
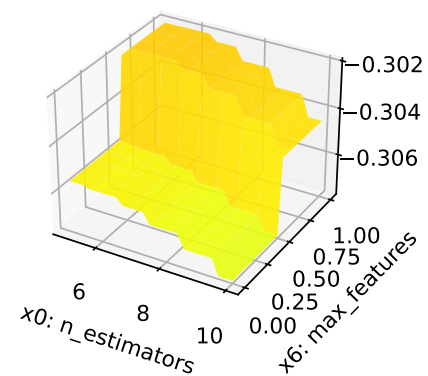
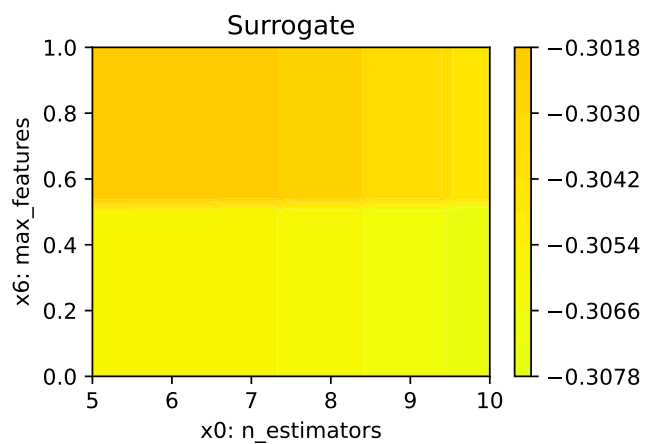
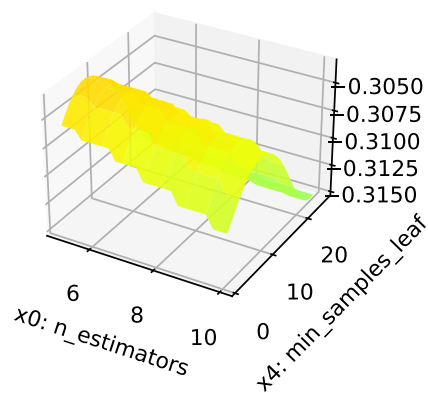
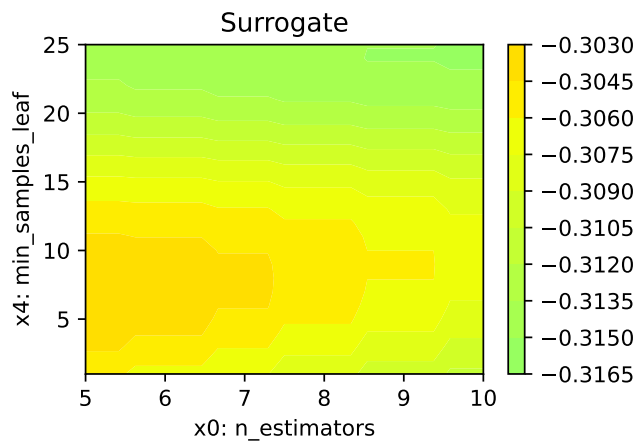
```

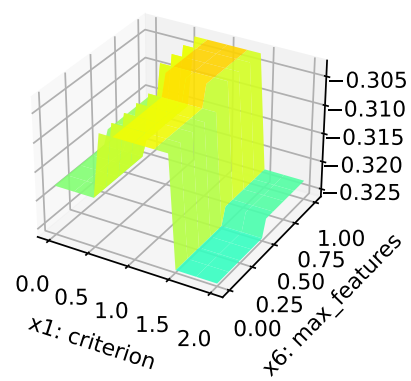
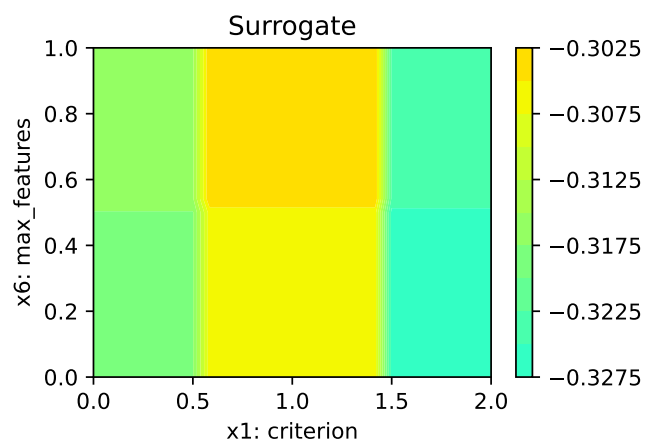
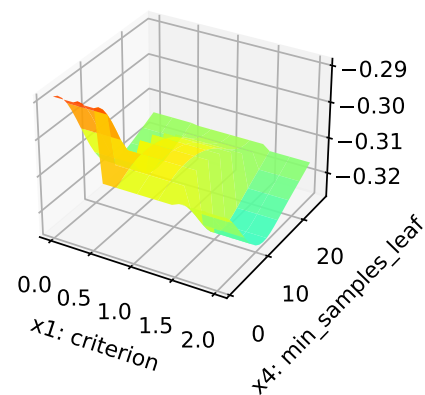
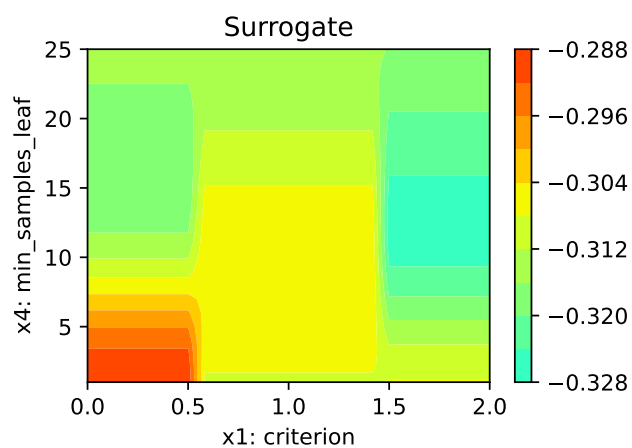
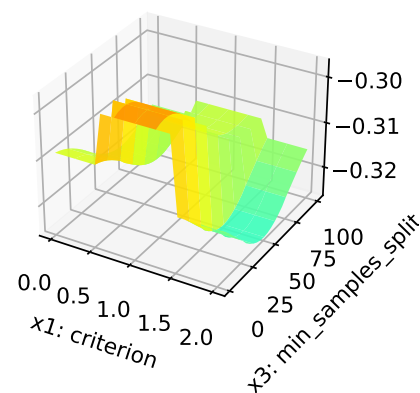
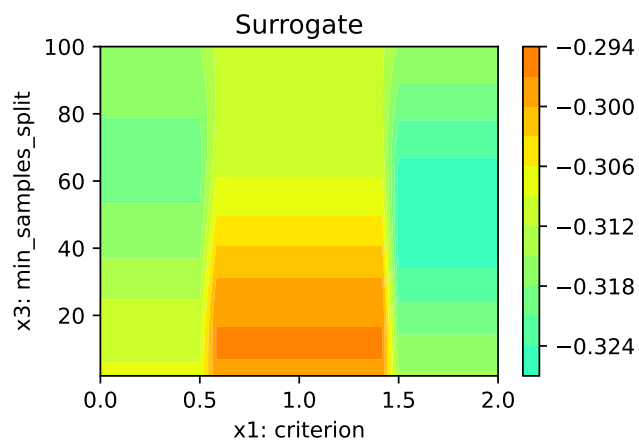
```

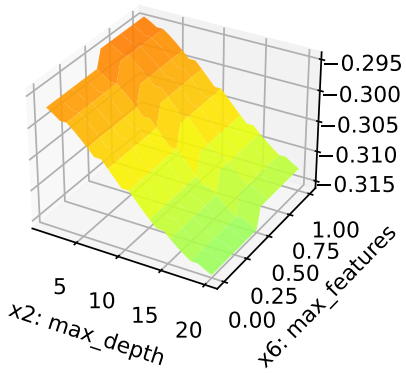
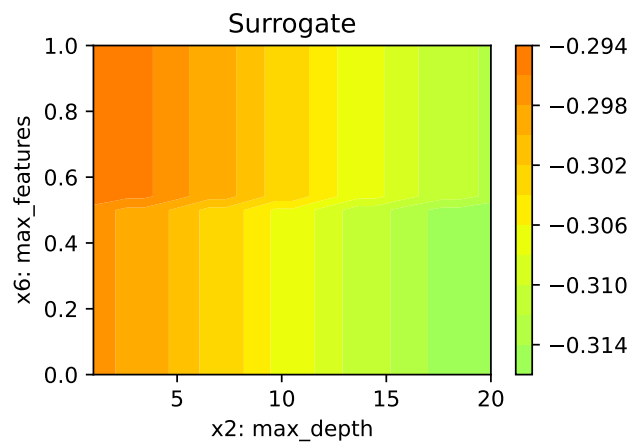
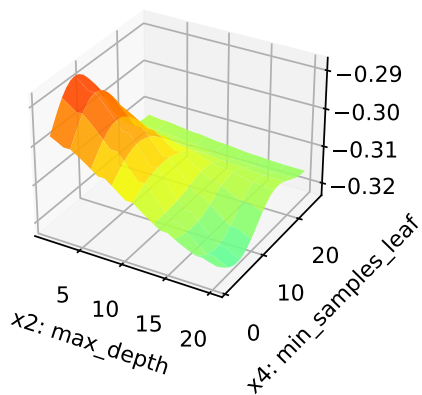
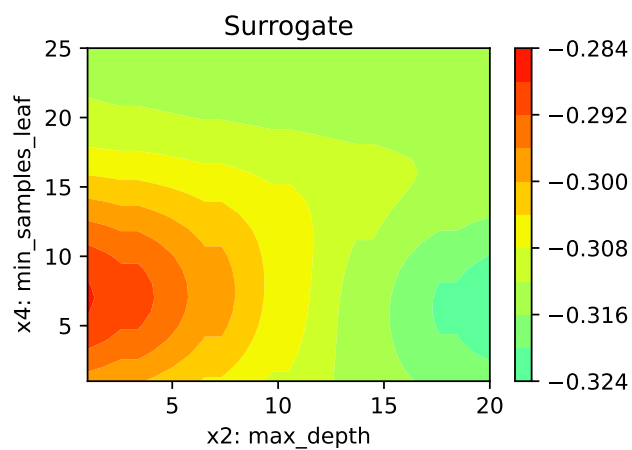
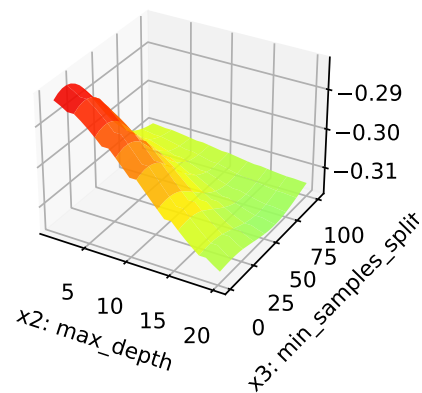
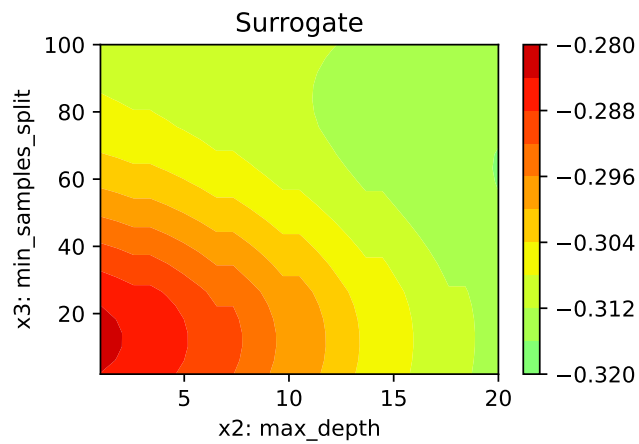
n_estimators: 4.29616772877326
criterion: 5.841472248728804
max_depth: 13.952946964814346
min_samples_split: 50.82400379058885
min_samples_leaf: 100.0
max_features: 0.7804639314403174

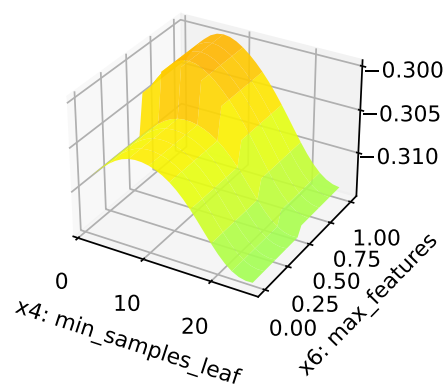
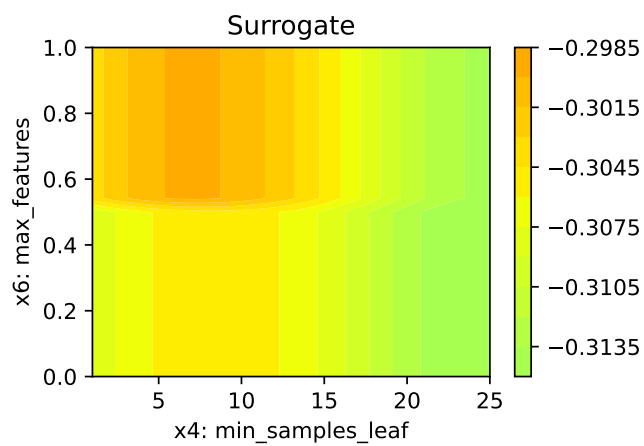
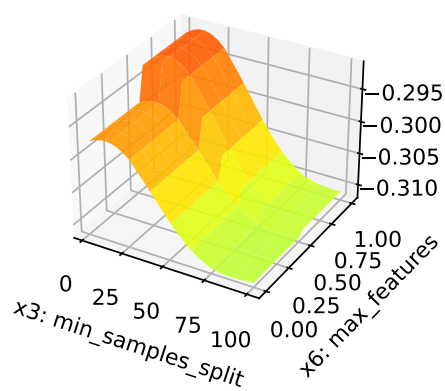
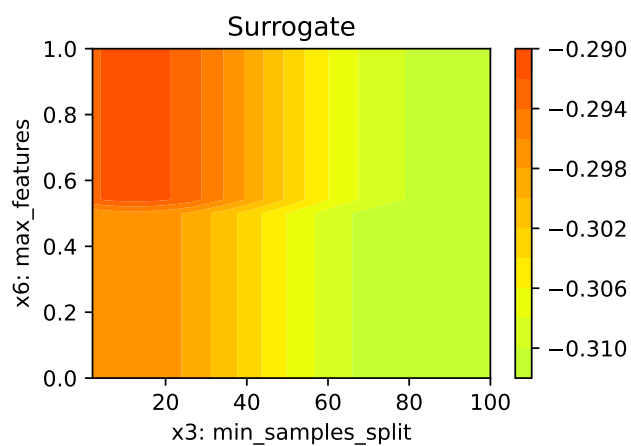
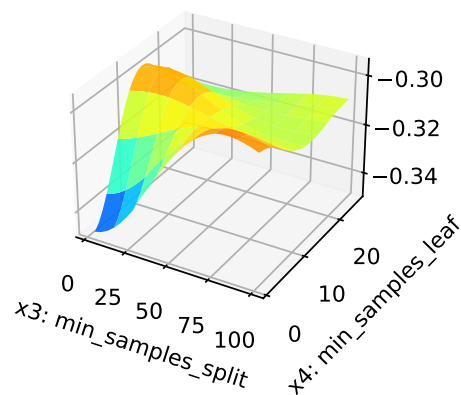
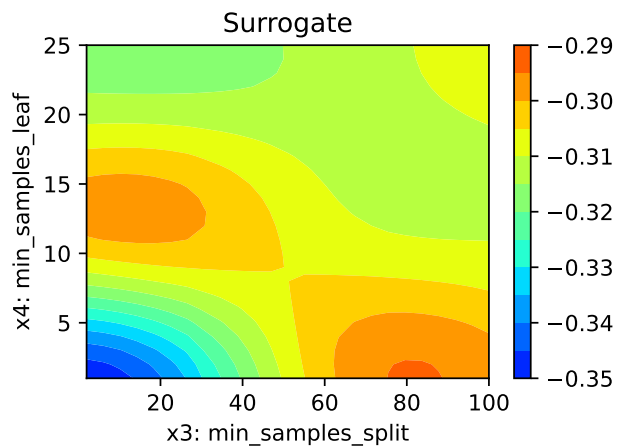
```











13.10.10 Parallel Coordinates Plot

```
spot_tuner.parallel_plot()
```

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Unable to display output for mime type(s): text/html

13.10.11 Plot all Combinations of Hyperparameters

- Warning: this may take a while.

```
PLOT_ALL = False
if PLOT_ALL:
    n = spot_tuner.k
    for i in range(n-1):
        for j in range(i+1, n):
            spot_tuner.plot_contour(i=i, j=j, min_z=min_z, max_z = max_z)
```

14 HPT: sklearn XGB Classifier VBDP Data

spotPython can be installed via pip. Alternatively, the source code can be downloaded from gitHub: <https://github.com/sequential-parameter-optimization/spotPython>.

```
!pip install spotPython
```

- Uncomment the following lines if you want to for (re-)installation the latest version of spotPython from gitHub.

```
# import sys
# !{sys.executable} -m pip install --upgrade build
# !{sys.executable} -m pip install --upgrade --force-reinstall spotPython
```

14.1 Step 1: Setup

Before we consider the detailed experimental setup, we select the parameters that affect run time and the initial design size.

```
MAX_TIME = 1
INIT_SIZE = 5
ORIGINAL = False
PREFIX = "17"
```

```
import warnings
warnings.filterwarnings("ignore")
```


14.2 Step 2: Initialization of the Empty fun_control Dictionary

```
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_experiment_name, get_spot_tensorboard_path
from spotPython.utils.device import getDevice

experiment_name = get_experiment_name(prefix=PREFIX)

fun_control = fun_control_init(
    task="classification",
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name))
```

14.3 Step 3: PyTorch Data Loading

14.3.1 1. Load Data: Classification VBDP

```
import pandas as pd
if ORIGINAL == True:
    train_df = pd.read_csv('./data/VBDP/trainnn.csv')
    test_df = pd.read_csv('./data/VBDP/testtt.csv')
else:
    train_df = pd.read_csv('./data/VBDP/train.csv')
    # remove the id column
    train_df = train_df.drop(columns=['id'])

from sklearn.preprocessing import OrdinalEncoder
n_samples = train_df.shape[0]
n_features = train_df.shape[1] - 1
target_column = "prognosis"
# Encoder our prognosis labels as integers for easier decoding later
enc = OrdinalEncoder()
train_df[target_column] = enc.fit_transform(train_df[[target_column]])
train_df.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
print(train_df.shape)
train_df.head()
```

(707, 65)

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19
0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	1.0
1	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0
2	0.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0
3	0.0	0.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	1.0	1.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The full data set `train_df` 64 features. The target column is labeled as `prognosis`.

14.3.2 Holdout Train and Test Data

We split out a hold-out test set (25% of the data) so we can calculate an example MAP@K

```
import numpy as np
from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = train_test_split(train_df.drop(target_column, axis=1),
                                                    random_state=42,
                                                    test_size=0.25,
                                                    stratify=train_df[target_column])
train = pd.DataFrame(np.hstack((X_train, np.array(y_train).reshape(-1, 1))))
test = pd.DataFrame(np.hstack((X_test, np.array(y_test).reshape(-1, 1))))
train.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
test.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
print(train.shape)
print(test.shape)
train.head()
```

(530, 65)

(177, 65)

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19
0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0
2	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0
4	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0

```
# add the dataset to the fun_control
fun_control.update({"data": train_df, # full dataset,
                  "train": train,
```

```

    "test": test,
    "n_samples": n_samples,
    "target_column": target_column})

```

14.4 Step 4: Specification of the Preprocessing Model

Data preprocessing can be very simple, e.g., you can ignore it. Then you would choose the `prep_model` "None":

```

prep_model = None
fun_control.update({"prep_model": prep_model})

```

A default approach for numerical data is the `StandardScaler` (mean 0, variance 1). This can be selected as follows:

```

# prep_model = StandardScaler()
# fun_control.update({"prep_model": prep_model})

```

Even more complicated pre-processing steps are possible, e.g., the following pipeline:

```

# categorical_columns = []
# one_hot_encoder = OneHotEncoder(handle_unknown="ignore", sparse_output=False)
# prep_model = ColumnTransformer(
#     transformers=[
#         ("categorical", one_hot_encoder, categorical_columns),
#     ],
#     remainder=StandardScaler(),
# )

```

14.5 Step 5: Select Model (algorithm) and `core_model_hyper_dict`

The selection of the algorithm (ML model) that should be tuned is done by specifying the its name from the `sklearn` implementation. For example, the `SVC` support vector machine classifier is selected as follows:

```

add_core_model_to_fun_control(SVC, fun_control, SklearnHyperDict)

```

Other `core_models` are, e.g.,:

- RidgeCV
- GradientBoostingRegressor
- ElasticNet
- RandomForestClassifier
- LogisticRegression
- KNeighborsClassifier
- RandomForestClassifier
- GradientBoostingClassifier
- HistGradientBoostingClassifier

We will use the `RandomForestClassifier` classifier in this example.

```
from sklearn.linear_model import RidgeCV
from sklearn.ensemble import RandomForestClassifier
from sklearn.svm import SVC
from sklearn.linear_model import LogisticRegression
from sklearn.neighbors import KNeighborsClassifier
from sklearn.ensemble import GradientBoostingClassifier
from sklearn.ensemble import GradientBoostingRegressor
from sklearn.ensemble import HistGradientBoostingClassifier
from sklearn.linear_model import ElasticNet
from spotPython.hyperparameters.values import add_core_model_to_fun_control
from spotPython.data.sklearn_hyper_dict import SklearnHyperDict
from spotPython.fun.hypersklearn import HyperSklearn

# core_model = RidgeCV
# core_model = GradientBoostingRegressor
# core_model = ElasticNet
core_model = RandomForestClassifier
# core_model = SVC
# core_model = LogisticRegression
# core_model = KNeighborsClassifier
# core_model = GradientBoostingClassifier
core_model = HistGradientBoostingClassifier
add_core_model_to_fun_control(core_model=core_model,
                             fun_control=fun_control,
                             hyper_dict=SklearnHyperDict,
                             filename=None)
```

Now `fun_control` has the information from the JSON file. The available hyperparameters are:

```
print(*fun_control["core_model_hyper_dict"].keys(), sep="\n")
```

```
loss
learning_rate
max_iter
max_leaf_nodes
max_depth
min_samples_leaf
l2_regularization
max_bins
early_stopping
n_iter_no_change
tol
```

14.6 Step 6: Modify hyper_dict Hyperparameters for the Selected Algorithm aka core_model

14.6.1 Modify hyperparameter of type numeric and integer (boolean)

Numeric and boolean values can be modified using the `modify_hyper_parameter_bounds` method. For example, to change the `tol` hyperparameter of the SVC model to the interval `[1e-3, 1e-2]`, the following code can be used:

```
modify_hyper_parameter_bounds(fun_control, "tol", bounds=[1e-3, 1e-2])
```

```
from spotPython.hyperparameters.values import modify_hyper_parameter_bounds
# modify_hyper_parameter_bounds(fun_control, "tol", bounds=[1e-3, 1e-2])
# modify_hyper_parameter_bounds(fun_control, "min_samples_split", bounds=[3, 20])
# modify_hyper_parameter_bounds(fun_control, "dual", bounds=[0, 0])
# modify_hyper_parameter_bounds(fun_control, "probability", bounds=[1, 1])
# fun_control["core_model_hyper_dict"]["tol"]
# modify_hyper_parameter_bounds(fun_control, "min_samples_leaf", bounds=[1, 25])
# modify_hyper_parameter_bounds(fun_control, "n_estimators", bounds=[5, 10])
```

14.6.2 Modify hyperparameter of type factor

`spotPython` provides functions for modifying the hyperparameters, their bounds and factors as well as for activating and de-activating hyperparameters without re-compilation of the Python source code. These functions were described in [Section 12.6](#).

Factors can be modified with the `modify_hyper_parameter_levels` function. For example, to exclude the `sigmoid` kernel from the tuning, the `kernel` hyperparameter of the `SVC` model can be modified as follows:

```
modify_hyper_parameter_levels(fun_control, "kernel", ["linear", "rbf"])
```

The new setting can be controlled via:

```
fun_control["core_model_hyper_dict"]["kernel"]
```

```
from spotPython.hyperparameters.values import modify_hyper_parameter_levels
# XGBoost:
modify_hyper_parameter_levels(fun_control, "loss", ["log_loss"])
```

14.6.3 Optimizers

Optimizers are described in Section [12.6.1](#).

14.7 Step 7: Selection of the Objective (Loss) Function

14.7.1 Evaluation

The evaluation procedure requires the specification of two elements:

1. the way how the data is split into a train and a test set and
2. the loss function (and a metric).

14.7.2 Selection of the Objective: Metric and Loss Functions

- Machine learning models are optimized with respect to a metric, for example, the `accuracy` function.
- Deep learning, e.g., neural networks are optimized with respect to a loss function, for example, the `cross_entropy` function and evaluated with respect to a metric, for example, the `accuracy` function.

14.7.3 Loss Function

The loss function, that is usually used in deep learning for optimizing the weights of the net, is stored in the `fun_control` dictionary as `"loss_function"`.

14.7.4 Metric Function

There are two different types of metrics in `spotPython`:

1. "metric_river" is used for the river based evaluation via `eval_oml_iter_progressive`.
2. "metric_sklearn" is used for the sklearn based evaluation.

We will consider multi-class classification metrics, e.g., `mapk_score` and `top_k_accuracy_score`.

Predict Probabilities

In this multi-class classification example the machine learning algorithm should return the probabilities of the specific classes ("`predict_proba`") instead of the predicted values.

We set "`predict_proba`" to `True` in the `fun_control` dictionary.

14.7.4.1 The MAPK Metric

To select the MAPK metric, the following two entries can be added to the `fun_control` dictionary:

```
"metric_sklearn": mapk_score"
```

```
"metric_params": {"k": 3}.
```

14.7.4.2 Other Metrics

Alternatively, other metrics for multi-class classification can be used, e.g., * `top_k_accuracy_score` or * `roc_auc_score`

The metric `roc_auc_score` requires the parameter "`multi_class`", e.g.,

```
"multi_class": "ovr".
```

This is set in the `fun_control` dictionary.

Weights

`spotPython` performs a minimization, therefore, metrics that should be maximized have to be multiplied by -1. This is done by setting "`weights`" to -1.

- The complete setup for the metric in our example is:

```

from spotPython.utils.metrics import mapk_score
fun_control.update({
    "weights": -1,
    "metric_sklearn": mapk_score,
    "predict_proba": True,
    "metric_params": {"k": 3},
})

```

14.7.5 Evaluation on Hold-out Data

- The default method for computing the performance is "eval_holdout".
- Alternatively, cross-validation can be used for every machine learning model.
- Specifically for RandomForests, the OOB-score can be used.

```

fun_control.update({
    "eval": "train_hold_out",
})

```

14.7.5.1 Cross Validation

Instead of using the OOB-score, the classical cross validation can be used. The number of folds is set by the key "k_folds". For example, to use 5-fold cross validation, the key "k_folds" is set to 5. Uncomment the following line to use cross validation:

```

# fun_control.update({
#     "eval": "train_cv",
#     "k_folds": 10,
# })

```

14.8 Step 8: Calling the SPOT Function

14.8.1 Preparing the SPOT Call

- Get types and variable names as well as lower and upper bounds for the hyperparameters.

```

# extract the variable types, names, and bounds
from spotPython.hyperparameters.values import (get_bound_values,
    get_var_name,

```



```

    get_var_type,)
var_type = get_var_type(fun_control)
var_name = get_var_name(fun_control)
lower = get_bound_values(fun_control, "lower")
upper = get_bound_values(fun_control, "upper")

from spotPython.utils.eda import gen_design_table
print(gen_design_table(fun_control))

```

name	type	default	lower	upper	transform
loss	factor	log_loss	0	0	None
learning_rate	float	-1.0	-5	0	transform_power_10
max_iter	int	7	3	10	transform_power_2_int
max_leaf_nodes	int	5	1	12	transform_power_2_int
max_depth	int	2	1	20	transform_power_2_int
min_samples_leaf	int	4	2	10	transform_power_2_int
l2_regularization	float	0.0	0	10	None
max_bins	int	255	127	255	None
early_stopping	factor	1	0	1	None
n_iter_no_change	int	10	5	20	None
tol	float	0.0001	1e-05	0.001	None

14.8.2 The Objective Function

The objective function is selected next. It implements an interface from `sklearn`'s training, validation, and testing methods to `spotPython`.

```

from spotPython.fun.hypersklearn import HyperSklearn
fun = HyperSklearn().fun_sklearn

```

14.8.3 Run the Spot Optimizer

- Run SPOT for approx. x mins (`max_time`).
- Note: the run takes longer, because the evaluation time of initial design (here: `initi_size`, 20 points) is not considered.

```

from spotPython.hyperparameters.values import get_default_hyperparameters_as_array
X_start = get_default_hyperparameters_as_array(fun_control)
X_start

```

```

array([[ 0.00e+00, -1.00e+00,  7.00e+00,  5.00e+00,  2.00e+00,  4.00e+00,
         0.00e+00,  2.55e+02,  1.00e+00,  1.00e+01,  1.00e-04]])

```

```

import numpy as np
from spotPython.spot import spot
from math import inf
spot_tuner = spot.Spot(fun=fun,
                        lower = lower,
                        upper = upper,
                        fun_evals = inf,
                        fun_repeats = 1,
                        max_time = MAX_TIME,
                        noise = False,
                        tolerance_x = np.sqrt(np.spacing(1)),
                        var_type = var_type,
                        var_name = var_name,
                        infill_criterion = "y",
                        n_points = 1,
                        seed=123,
                        log_level = 50,
                        show_models= False,
                        show_progress= True,
                        fun_control = fun_control,
                        design_control={"init_size": INIT_SIZE,
                                      "repeats": 1},
                        surrogate_control={"noise": True,
                                          "cod_type": "norm",
                                          "min_theta": -4,
                                          "max_theta": 3,
                                          "n_theta": len(var_name),
                                          "model_fun_evals": 10_000,
                                          "log_level": 50
                                          })

spot_tuner.run(X_start=X_start)

```

```

spotPython tuning: -0.40225563909774437 [-----] 4.51%

```

```

spotPython tuning: -0.40225563909774437 [#-----] 6.63%

spotPython tuning: -0.40225563909774437 [##-----] 17.81%

spotPython tuning: -0.40225563909774437 [##-----] 20.69%

spotPython tuning: -0.40225563909774437 [##-----] 22.45%

spotPython tuning: -0.40225563909774437 [###-----] 30.93%

spotPython tuning: -0.40225563909774437 [###-----] 34.53%

spotPython tuning: -0.40225563909774437 [####-----] 38.65%

spotPython tuning: -0.40225563909774437 [####-----] 42.71%

spotPython tuning: -0.40225563909774437 [#####-----] 52.98%

spotPython tuning: -0.40225563909774437 [#####-----] 84.98%

spotPython tuning: -0.40225563909774437 [#####-----] 88.27%

spotPython tuning: -0.40225563909774437 [#####-----] 98.43%

spotPython tuning: -0.40225563909774437 [#####-----] 100.00% Done...

<spotPython.spot.spot.Spot at 0x2a89a9900>

```

14.9 Step 9: Tensorboard

The textual output shown in the console (or code cell) can be visualized with Tensorboard as described in Section 12.9, see also the description in the documentation: [Tensorboard](#).

14.10 Step 10: Results

After the hyperparameter tuning run is finished, the progress of the hyperparameter tuning can be visualized. The following code generates the progress plot from `?@fig-progress`.

```
spot_tuner.plot_progress(log_y=False,
                        filename="./figures/" + experiment_name+"_progress.png")
```

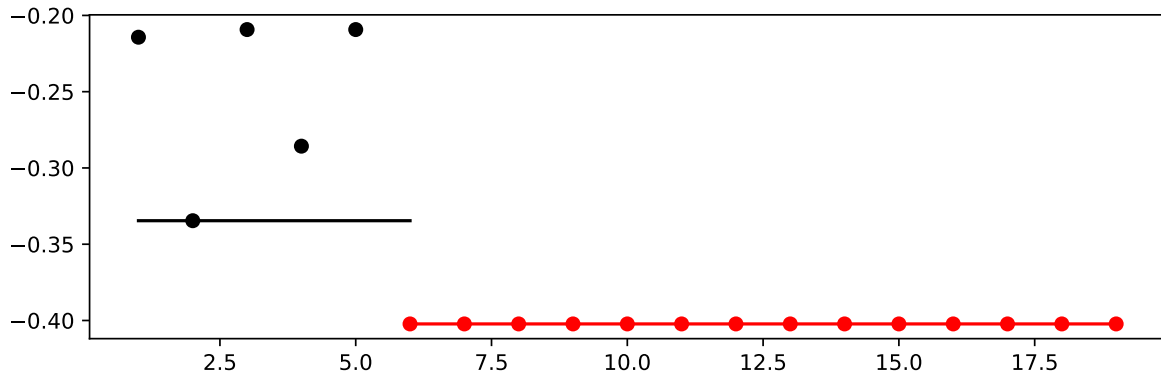


Figure 14.1: Progress plot. *Black* dots denote results from the initial design. *Red* dots illustrate the improvement found by the surrogate model based optimization.

- Print the results

```
print(gen_design_table(fun_control=fun_control,
                      spot=spot_tuner))
```

name	type	default	lower	upper	tuned	trans
loss	factor	log_loss	0.0	0.0	0.0	None
learning_rate	float	-1.0	-5.0	0.0	-0.9302847195992566	trans
max_iter	int	7	3.0	10.0	9.0	trans
max_leaf_nodes	int	5	1.0	12.0	5.0	trans
max_depth	int	2	1.0	20.0	19.0	trans
min_samples_leaf	int	4	2.0	10.0	2.0	trans
l2_regularization	float	0.0	0.0	10.0	2.4029083174155397	None
max_bins	int	255	127.0	255.0	142.0	None
early_stopping	factor	1	0.0	1.0	1.0	None
n_iter_no_change	int	10	5.0	20.0	6.0	None
tol	float	0.0001	1e-05	0.001	0.0009512857229213784	None

14.10.1 Show variable importance

```
spot_tuner.plot_importance(threshold=0.025, filename="./figures/" + experiment_name+"_impo
```

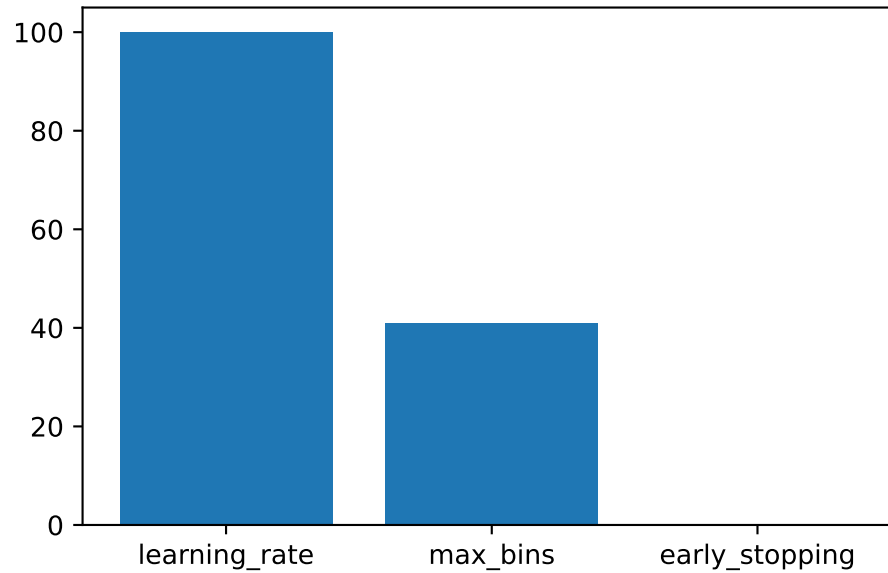


Figure 14.2: Variable importance plot, threshold 0.025.

14.10.2 Get Default Hyperparameters

```
from spotPython.hyperparameters.values import get_default_values, transform_hyper_parameter_values_default = get_default_values(fun_control)
values_default = transform_hyper_parameter_values(fun_control=fun_control, hyper_parameter_values_default
```

```
{'loss': 'log_loss',
 'learning_rate': 0.1,
 'max_iter': 128,
 'max_leaf_nodes': 32,
 'max_depth': 4,
 'min_samples_leaf': 16,
 'l2_regularization': 0.0,
 'max_bins': 255,
 'early_stopping': 1,
```

```
'n_iter_no_change': 10,
'tol': 0.0001}
```

```
from sklearn.pipeline import make_pipeline
model_default = make_pipeline(fun_control["prep_model"], fun_control["core_model"](**value
model_default
```

```
Pipeline(steps=[('nonetype', None),
                 ('histgradientboostingclassifier',
                  HistGradientBoostingClassifier(early_stopping=1, max_depth=4,
                                                  max_iter=128, max_leaf_nodes=32,
                                                  min_samples_leaf=16,
                                                  tol=0.0001))])])
```

14.10.3 Get SPOT Results

```
X = spot_tuner.to_all_dim(spot_tuner.min_X.reshape(1,-1))
print(X)
```

```
[[ 0.00000000e+00 -9.30284720e-01  9.00000000e+00  5.00000000e+00
  1.90000000e+01  2.00000000e+00  2.40290832e+00  1.42000000e+02
  1.00000000e+00  6.00000000e+00  9.51285723e-04]]
```

```
from spotPython.hyperparameters.values import assign_values, return_conf_list_from_var_dict
v_dict = assign_values(X, fun_control["var_name"])
return_conf_list_from_var_dict(var_dict=v_dict, fun_control=fun_control)
```

```
[{'loss': 'log_loss',
 'learning_rate': 0.11741275549834451,
 'max_iter': 512,
 'max_leaf_nodes': 32,
 'max_depth': 524288,
 'min_samples_leaf': 4,
 'l2_regularization': 2.4029083174155397,
 'max_bins': 142,
 'early_stopping': 1,
 'n_iter_no_change': 6,
 'tol': 0.0009512857229213784}]
```

```

from spotPython.hyperparameters.values import get_one_sklearn_model_from_X
model_spot = get_one_sklearn_model_from_X(X, fun_control)
model_spot

```

```

HistGradientBoostingClassifier(early_stopping=1,
                                l2_regularization=2.4029083174155397,
                                learning_rate=0.11741275549834451, max_bins=142,
                                max_depth=524288, max_iter=512,
                                max_leaf_nodes=32, min_samples_leaf=4,
                                n_iter_no_change=6, tol=0.0009512857229213784)

```

14.10.4 Evaluate SPOT Results

- Fetch the data.

```

from spotPython.utils.convert import get_Xy_from_df
X_train, y_train = get_Xy_from_df(fun_control["train"], fun_control["target_column"])
X_test, y_test = get_Xy_from_df(fun_control["test"], fun_control["target_column"])
X_test.shape, y_test.shape

```

```
((177, 64), (177,))
```

- Fit the model with the tuned hyperparameters. This gives one result:

```

model_spot.fit(X_train, y_train)
y_pred = model_spot.predict_proba(X_test)
res = mapk_score(y_true=y_test, y_pred=y_pred, k=3)
res

```

```
0.3418079096045198
```

```

def repeated_eval(n, model):
    res_values = []
    for i in range(n):
        model.fit(X_train, y_train)
        y_pred = model.predict_proba(X_test)
        res = mapk_score(y_true=y_test, y_pred=y_pred, k=3)
        res_values.append(res)
    mean_res = np.mean(res_values)

```

```

print(f"mean_res: {mean_res}")
std_res = np.std(res_values)
print(f"std_res: {std_res}")
min_res = np.min(res_values)
print(f"min_res: {min_res}")
max_res = np.max(res_values)
print(f"max_res: {max_res}")
median_res = np.median(res_values)
print(f"median_res: {median_res}")
return mean_res, std_res, min_res, max_res, median_res

```

14.10.5 Handling Non-deterministic Results

- Because the model is non-deterministic, we perform $n = 30$ runs and calculate the mean and standard deviation of the performance metric.

```
_ = repeated_eval(30, model_spot)
```

```

mean_res: 0.33945386064030125
std_res: 0.014597128426052378
min_res: 0.3060263653483992
max_res: 0.37099811676082856
median_res: 0.3408662900188324

```

14.10.6 Evaluation of the Default Hyperparameters

```
model_default.fit(X_train, y_train)["histgradientboostingclassifier"]
```

```

HistGradientBoostingClassifier(early_stopping=1, max_depth=4, max_iter=128,
                                max_leaf_nodes=32, min_samples_leaf=16,
                                tol=0.0001)

```

- One evaluation of the default hyperparameters is performed on the hold-out test set.

```

y_pred = model_default.predict_proba(X_test)
mapk_score(y_true=y_test, y_pred=y_pred, k=3)

```

```
0.3361581920903955
```

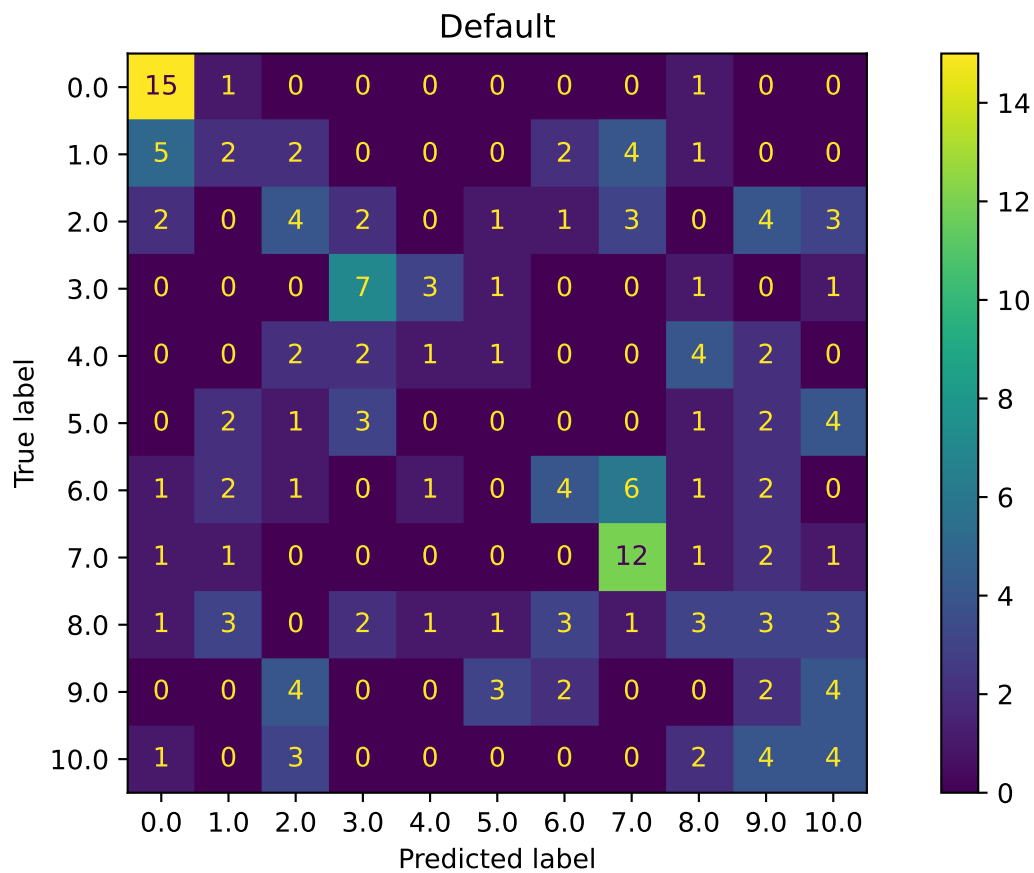

Since one single evaluation is not meaningful, we perform, similar to the evaluation of the SPOT results, $n = 30$ runs of the default setting and calculate the mean and standard deviation of the performance metric.

```
_ = repeated_eval(30, model_default)
```

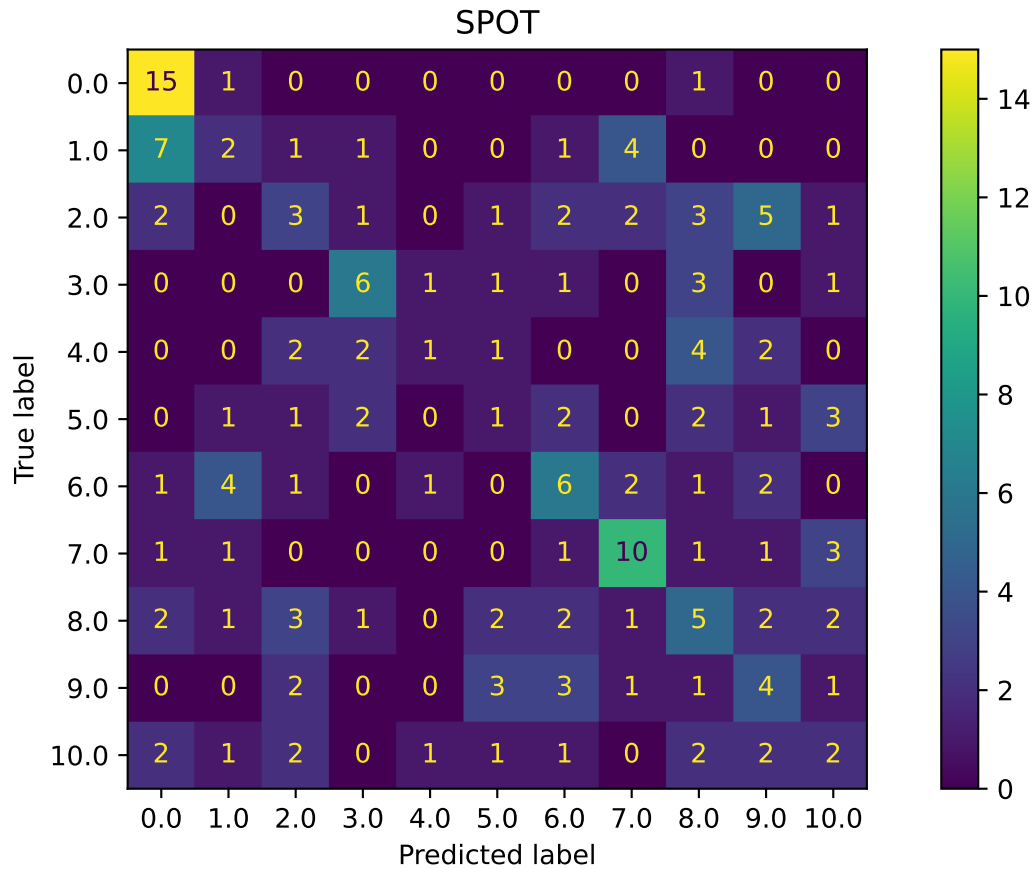
```
mean_res: 0.34808537350910235
std_res: 0.016295430582978773
min_res: 0.3163841807909605
max_res: 0.38229755178907715
median_res: 0.3498116760828625
```

14.10.7 Plot: Compare Predictions

```
from spotPython.plot.validation import plot_confusion_matrix
plot_confusion_matrix(model_default, fun_control, title = "Default")
```



```
plot_confusion_matrix(model_spot, fun_control, title="SPOT")
```



```
min(spot_tuner.y), max(spot_tuner.y)
```

```
(-0.40225563909774437, -0.20927318295739344)
```

14.10.8 Cross-validated Evaluations

```
from spotPython.sklearn.traintest import evaluate_cv
fun_control.update({
    "eval": "train_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)
```

```
(0.34874213836477985, None)
```

```

fun_control.update({
    "eval": "test_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)

```

(0.2627450980392157, None)

- This is the evaluation that will be used in the comparison:

```

fun_control.update({
    "eval": "data_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)

```

(0.33968477531857816, None)

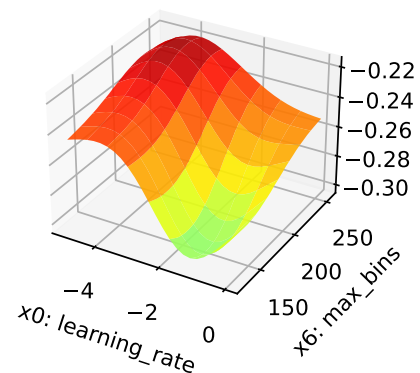
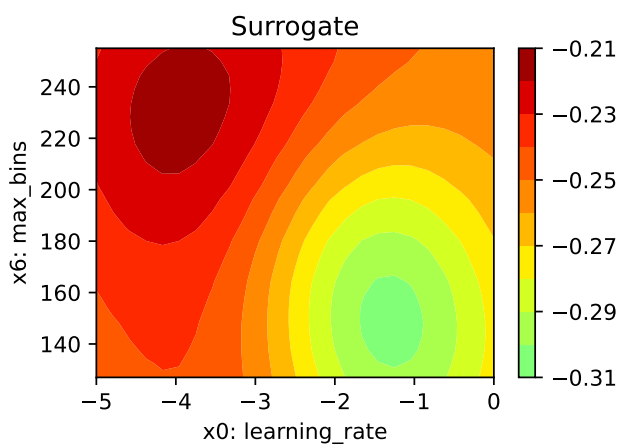
14.10.9 Detailed Hyperparameter Plots

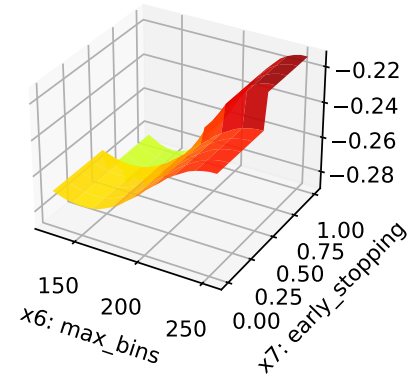
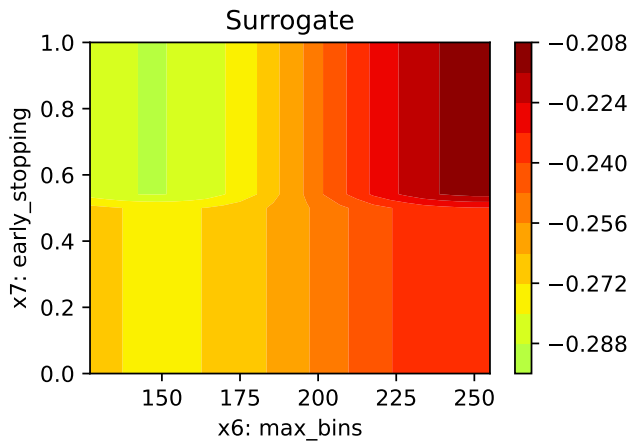
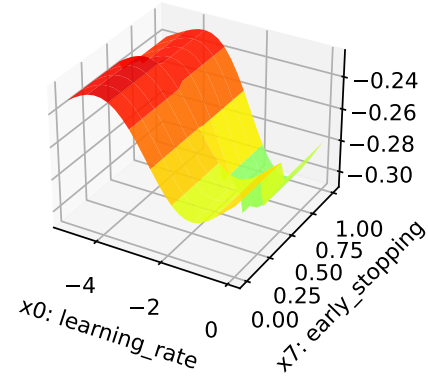
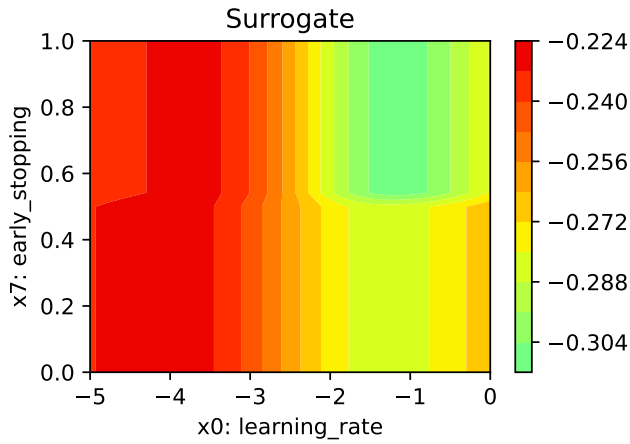
```

filename = "./figures/" + experiment_name
spot_tuner.plot_important_hyperparameter_contour(filename=filename)

```

learning_rate: 100.0
 max_bins: 40.88105458083755
 early_stopping: 0.14250069746648705





14.10.10 Parallel Coordinates Plot

```
spot_tuner.parallel_plot()
```

Unable to display output for mime type(s): text/html

Unable to display output for mime type(s): text/html

14.10.11 Plot all Combinations of Hyperparameters

- Warning: this may take a while.

```
PLOT_ALL = False
if PLOT_ALL:
    n = spot_tuner.k
    for i in range(n-1):
        for j in range(i+1, n):
            spot_tuner.plot_contour(i=i, j=j, min_z=min_z, max_z = max_z)
```

15 HPT: sklearn SVC VBDP Data

spotPython can be installed via pip. Alternatively, the source code can be downloaded from gitHub: <https://github.com/sequential-parameter-optimization/spotPython>.

```
!pip install spotPython
```

- Uncomment the following lines if you want to for (re-)installation the latest version of spotPython from gitHub.

```
# import sys
# !{sys.executable} -m pip install --upgrade build
# !{sys.executable} -m pip install --upgrade --force-reinstall spotPython
```

15.1 Step 1: Setup

Before we consider the detailed experimental setup, we select the parameters that affect run time and the initial design size.

```
MAX_TIME = 1
INIT_SIZE = 5
ORIGINAL = False
PREFIX = "18"

import warnings
warnings.filterwarnings("ignore")
```

15.2 Step 2: Initialization of the Empty fun_control Dictionary

```
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_experiment_name, get_spot_tensorboard_path
from spotPython.utils.device import getDevice

experiment_name = get_experiment_name(prefix=PREFIX)

fun_control = fun_control_init(
    task="classification",
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name))
```

15.3 Step 3: PyTorch Data Loading

15.3.1 1. Load Data: Classification VBDP

```
import pandas as pd
if ORIGINAL == True:
    train_df = pd.read_csv('./data/VBDP/trainnn.csv')
    test_df = pd.read_csv('./data/VBDP/testtt.csv')
else:
    train_df = pd.read_csv('./data/VBDP/train.csv')
    # remove the id column
    train_df = train_df.drop(columns=['id'])

from sklearn.preprocessing import OrdinalEncoder
n_samples = train_df.shape[0]
n_features = train_df.shape[1] - 1
target_column = "prognosis"
# Encoder our prognosis labels as integers for easier decoding later
enc = OrdinalEncoder()
train_df[target_column] = enc.fit_transform(train_df[[target_column]])
train_df.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
print(train_df.shape)
train_df.head()
```

(707, 65)

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19
0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	1.0
1	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0
2	0.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0
3	0.0	0.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	1.0	1.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The full data set `train_df` 64 features. The target column is labeled as `prognosis`.

15.3.2 Holdout Train and Test Data

We split out a hold-out test set (25% of the data) so we can calculate an example MAP@K

```
import numpy as np
from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = train_test_split(train_df.drop(target_column, axis=1),
                                                    random_state=42,
                                                    test_size=0.25,
                                                    stratify=train_df[target_column])
train = pd.DataFrame(np.hstack((X_train, np.array(y_train).reshape(-1, 1))))
test = pd.DataFrame(np.hstack((X_test, np.array(y_test).reshape(-1, 1))))
train.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
test.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
print(train.shape)
print(test.shape)
train.head()
```

(530, 65)

(177, 65)

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19
0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0
2	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0
4	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0

```
# add the dataset to the fun_control
fun_control.update({"data": train_df, # full dataset,
                   "train": train,
```

```

        "test": test,
        "n_samples": n_samples,
        "target_column": target_column})

```

15.4 Step 4: Specification of the Preprocessing Model

Data preprocessing can be very simple, e.g., you can ignore it. Then you would choose the `prep_model` "None":

```

prep_model = None
fun_control.update({"prep_model": prep_model})

```

A default approach for numerical data is the `StandardScaler` (mean 0, variance 1). This can be selected as follows:

```

# prep_model = StandardScaler()
# fun_control.update({"prep_model": prep_model})

```

Even more complicated pre-processing steps are possible, e.g., the following pipeline:

```

# categorical_columns = []
# one_hot_encoder = OneHotEncoder(handle_unknown="ignore", sparse_output=False)
# prep_model = ColumnTransformer(
#     transformers=[
#         ("categorical", one_hot_encoder, categorical_columns),
#     ],
#     remainder=StandardScaler(),
# )

```

15.5 Step 5: Select Model (algorithm) and `core_model_hyper_dict`

The selection of the algorithm (ML model) that should be tuned is done by specifying the its name from the `sklearn` implementation. For example, the `SVC` support vector machine classifier is selected as follows:

```

add_core_model_to_fun_control(SVC, fun_control, SklearnHyperDict)

```

Other `core_models` are, e.g.,:

- RidgeCV
- GradientBoostingRegressor
- ElasticNet
- RandomForestClassifier
- LogisticRegression
- KNeighborsClassifier
- RandomForestClassifier
- GradientBoostingClassifier
- HistGradientBoostingClassifier

We will use the `RandomForestClassifier` classifier in this example.

```
from sklearn.linear_model import RidgeCV
from sklearn.ensemble import RandomForestClassifier
from sklearn.svm import SVC
from sklearn.linear_model import LogisticRegression
from sklearn.neighbors import KNeighborsClassifier
from sklearn.ensemble import GradientBoostingClassifier
from sklearn.ensemble import GradientBoostingRegressor
from sklearn.ensemble import HistGradientBoostingClassifier
from sklearn.linear_model import ElasticNet
from spotPython.hyperparameters.values import add_core_model_to_fun_control
from spotPython.data.sklearn_hyper_dict import SklearnHyperDict
from spotPython.fun.hypersklearn import HyperSklearn

# core_model = RidgeCV
# core_model = GradientBoostingRegressor
# core_model = ElasticNet
# core_model = RandomForestClassifier
core_model = SVC
# core_model = LogisticRegression
# core_model = KNeighborsClassifier
# core_model = GradientBoostingClassifier
# core_model = HistGradientBoostingClassifier
add_core_model_to_fun_control(core_model=core_model,
                             fun_control=fun_control,
                             hyper_dict=SklearnHyperDict,
                             filename=None)
```

Now `fun_control` has the information from the JSON file. The available hyperparameters are:

```
print(*fun_control["core_model_hyper_dict"].keys(), sep="\n")
```

```
C
kernel
degree
gamma
coef0
shrinking
probability
tol
cache_size
break_ties
```

15.6 Step 6: Modify hyper_dict Hyperparameters for the Selected Algorithm aka core_model

15.6.1 Modify hyperparameter of type numeric and integer (boolean)

Numeric and boolean values can be modified using the `modify_hyper_parameter_bounds` method. For example, to change the `tol` hyperparameter of the SVC model to the interval `[1e-3, 1e-2]`, the following code can be used:

```
modify_hyper_parameter_bounds(fun_control, "tol", bounds=[1e-3, 1e-2])
```

```
from spotPython.hyperparameters.values import modify_hyper_parameter_bounds
modify_hyper_parameter_bounds(fun_control, "probability", bounds=[1, 1])
```

15.6.2 Modify hyperparameter of type factor

`spotPython` provides functions for modifying the hyperparameters, their bounds and factors as well as for activating and de-activating hyperparameters without re-compilation of the Python source code. These functions were described in [Section 12.6](#).

Factors can be modified with the `modify_hyper_parameter_levels` function. For example, to exclude the `sigmoid` kernel from the tuning, the `kernel` hyperparameter of the SVC model can be modified as follows:

```
modify_hyper_parameter_levels(fun_control, "kernel", ["linear", "rbf"])
```

The new setting can be controlled via:

```
fun_control["core_model_hyper_dict"]["kernel"]

from spotPython.hyperparameters.values import modify_hyper_parameter_levels
modify_hyper_parameter_levels(fun_control, "kernel", ["rbf"])
```

15.6.3 Optimizers

Optimizers are described in Section [12.6.1](#).

15.6.4 Selection of the Objective: Metric and Loss Functions

- Machine learning models are optimized with respect to a metric, for example, the accuracy function.
- Deep learning, e.g., neural networks are optimized with respect to a loss function, for example, the `cross_entropy` function and evaluated with respect to a metric, for example, the accuracy function.

15.7 Step 7: Selection of the Objective (Loss) Function

The loss function, that is usually used in deep learning for optimizing the weights of the net, is stored in the `fun_control` dictionary as `"loss_function"`.

15.7.1 Metric Function

There are two different types of metrics in `spotPython`:

1. `"metric_river"` is used for the river based evaluation via `eval_oml_iter_progressive`.
2. `"metric_sklearn"` is used for the sklearn based evaluation.

We will consider multi-class classification metrics, e.g., `mapk_score` and `top_k_accuracy_score`.

Predict Probabilities

In this multi-class classification example the machine learning algorithm should return the probabilities of the specific classes (`"predict_proba"`) instead of the predicted values.

We set `"predict_proba"` to `True` in the `fun_control` dictionary.

15.7.1.1 The MAPK Metric

To select the MAPK metric, the following two entries can be added to the `fun_control` dictionary:

```
"metric_sklearn": mapk_score"  
"metric_params": {"k": 3}.
```

15.7.1.2 Other Metrics

Alternatively, other metrics for multi-class classification can be used, e.g., `* top_k_accuracy_score` or `* roc_auc_score`

The metric `roc_auc_score` requires the parameter `"multi_class"`, e.g.,

```
"multi_class": "ovr".
```

This is set in the `fun_control` dictionary.

Weights

`spotPython` performs a minimization, therefore, metrics that should be maximized have to be multiplied by -1. This is done by setting `"weights"` to -1.

- The complete setup for the metric in our example is:

```
from spotPython.utils.metrics import mapk_score  
fun_control.update({  
    "weights": -1,  
    "metric_sklearn": mapk_score,  
    "predict_proba": True,  
    "metric_params": {"k": 3},  
})
```

15.7.2 Evaluation on Hold-out Data

- The default method for computing the performance is `"eval_holdout"`.
- Alternatively, cross-validation can be used for every machine learning model.
- Specifically for RandomForests, the OOB-score can be used.

```
fun_control.update({
    "eval": "train_hold_out",
})
```

15.7.2.1 Cross Validation

Instead of using the OOB-score, the classical cross validation can be used. The number of folds is set by the key "k_folds". For example, to use 5-fold cross validation, the key "k_folds" is set to 5. Uncomment the following line to use cross validation:

```
# fun_control.update({
#     "eval": "train_cv",
#     "k_folds": 10,
# })
```

15.8 Step 8: Calling the SPOT Function

15.8.1 Preparing the SPOT Call

- Get types and variable names as well as lower and upper bounds for the hyperparameters.

```
# extract the variable types, names, and bounds
from spotPython.hyperparameters.values import (get_bound_values,
    get_var_name,
    get_var_type,)
var_type = get_var_type(fun_control)
var_name = get_var_name(fun_control)
lower = get_bound_values(fun_control, "lower")
upper = get_bound_values(fun_control, "upper")
```

```
from spotPython.utils.eda import gen_design_table
print(gen_design_table(fun_control))
```

name	type	default	lower	upper	transform
C	float	1.0	0.1	10	None
kernel	factor	rbf	0	0	None
degree	int	3	3	3	None

gamma	factor	scale	0	1	None	
coef0	float	0.0	0	0	None	
shrinking	factor	0	0	1	None	
probability	factor	0	1	1	None	
tol	float	0.001	0.0001	0.01	None	
cache_size	float	200.0	100	400	None	
break_ties	factor	0	0	1	None	

15.8.2 The Objective Function

The objective function is selected next. It implements an interface from `sklearn`'s training, validation, and testing methods to `spotPython`.

```
from spotPython.fun.hypersklearn import HyperSklearn
fun = HyperSklearn().fun_sklearn
```

15.8.3 Run the Spot Optimizer

- Run SPOT for approx. x mins (`max_time`).
- Note: the run takes longer, because the evaluation time of initial design (here: `init_size`, 20 points) is not considered.

```
from spotPython.hyperparameters.values import get_default_hyperparameters_as_array
X_start = get_default_hyperparameters_as_array(fun_control)
X_start
```

```
array([[1.e+00, 0.e+00, 3.e+00, 0.e+00, 0.e+00, 0.e+00, 0.e+00, 1.e-03,
        2.e+02, 0.e+00]])
```

```
import numpy as np
from spotPython.spot import spot
from math import inf
spot_tuner = spot.Spot(fun=fun,
                       lower = lower,
                       upper = upper,
                       fun_evals = inf,
                       fun_repeats = 1,
                       max_time = MAX_TIME,
                       noise = False,
```



```

tolerance_x = np.sqrt(np.spacing(1)),
var_type = var_type,
var_name = var_name,
infill_criterion = "y",
n_points = 1,
seed=123,
log_level = 50,
show_models= False,
show_progress= True,
fun_control = fun_control,
design_control={"init_size": INIT_SIZE,
               "repeats": 1},
surrogate_control={"noise": True,
                  "cod_type": "norm",
                  "min_theta": -4,
                  "max_theta": 3,
                  "n_theta": len(var_name),
                  "model_fun_evals": 10_000,
                  "log_level": 50
                })

spot_tuner.run(X_start=X_start)

```

```

spotPython tuning: -0.38345864661654133 [-----] 0.38%

spotPython tuning: -0.38345864661654133 [-----] 0.74%

spotPython tuning: -0.38345864661654133 [-----] 1.08%

spotPython tuning: -0.38345864661654133 [-----] 1.38%

spotPython tuning: -0.38345864661654133 [-----] 1.89%

spotPython tuning: -0.38345864661654133 [-----] 2.41%

spotPython tuning: -0.38345864661654133 [-----] 2.95%

spotPython tuning: -0.38345864661654133 [-----] 3.43%

spotPython tuning: -0.38345864661654133 [-----] 3.94%

```

spotPython tuning: -0.38345864661654133 [-----] 4.32%

spotPython tuning: -0.38345864661654133 [-----] 4.82%

spotPython tuning: -0.38345864661654133 [#-----] 5.27%

spotPython tuning: -0.38345864661654133 [#-----] 7.33%

spotPython tuning: -0.38345864661654133 [#-----] 8.21%

spotPython tuning: -0.38345864661654133 [#-----] 9.25%

spotPython tuning: -0.38345864661654133 [#-----] 9.91%

spotPython tuning: -0.38345864661654133 [#-----] 10.63%

spotPython tuning: -0.38345864661654133 [#-----] 11.33%

spotPython tuning: -0.38345864661654133 [#-----] 12.01%

spotPython tuning: -0.38345864661654133 [#-----] 12.81%

spotPython tuning: -0.38721804511278196 [#-----] 13.70%

spotPython tuning: -0.38721804511278196 [#-----] 14.81%

spotPython tuning: -0.38721804511278196 [##-----] 16.80%

spotPython tuning: -0.38721804511278196 [##-----] 17.73%

spotPython tuning: -0.38721804511278196 [##-----] 18.57%

spotPython tuning: -0.38721804511278196 [##-----] 19.55%

spotPython tuning: -0.38721804511278196 [##-----] 20.53%

spotPython tuning: -0.38721804511278196 [##-----] 21.33%

spotPython tuning: -0.38721804511278196 [##-----] 22.54%

spotPython tuning: -0.38721804511278196 [##-----] 23.66%

spotPython tuning: -0.38721804511278196 [###-----] 25.74%

spotPython tuning: -0.38721804511278196 [###-----] 27.20%

spotPython tuning: -0.38721804511278196 [###-----] 28.46%

spotPython tuning: -0.38721804511278196 [###-----] 30.10%

spotPython tuning: -0.39348370927318294 [###-----] 31.66%

spotPython tuning: -0.39348370927318294 [###-----] 33.00%

spotPython tuning: -0.39348370927318294 [###-----] 34.26%

spotPython tuning: -0.39348370927318294 [####-----] 36.59%

spotPython tuning: -0.39348370927318294 [####-----] 38.15%

spotPython tuning: -0.39348370927318294 [####-----] 39.78%

spotPython tuning: -0.39348370927318294 [####-----] 41.72%

spotPython tuning: -0.39348370927318294 [####-----] 43.37%

spotPython tuning: -0.39348370927318294 [#####-----] 45.93%

spotPython tuning: -0.39348370927318294 [#####-----] 47.71%

spotPython tuning: -0.39348370927318294 [#####-----] 49.23%

spotPython tuning: -0.39348370927318294 [#####-----] 50.78%

spotPython tuning: -0.39348370927318294 [#####-----] 52.08%

```

spotPython tuning: -0.39348370927318294 [#####-----] 54.41%

spotPython tuning: -0.39348370927318294 [#####-----] 55.89%

spotPython tuning: -0.39348370927318294 [#####-----] 57.61%

spotPython tuning: -0.39348370927318294 [#####-----] 59.77%

spotPython tuning: -0.39348370927318294 [#####-----] 61.68%

spotPython tuning: -0.39348370927318294 [#####-----] 64.73%

spotPython tuning: -0.39348370927318294 [#####-----] 66.80%

spotPython tuning: -0.39348370927318294 [#####-----] 69.31%

spotPython tuning: -0.39348370927318294 [#####-----] 73.46%

spotPython tuning: -0.39348370927318294 [#####-----] 75.81%

spotPython tuning: -0.39348370927318294 [#####-----] 78.22%

spotPython tuning: -0.39348370927318294 [#####-----] 100.00% Done...

<spotPython.spot.spot.Spot at 0x298345f00>

```

15.9 Step 9: Tensorboard

The textual output shown in the console (or code cell) can be visualized with Tensorboard as described in Section 12.9, see also the description in the documentation: [Tensorboard](#).

15.10 Step 10: Results

After the hyperparameter tuning run is finished, the progress of the hyperparameter tuning can be visualized. The following code generates the progress plot from `?@fig-progress`.

```
spot_tuner.plot_progress(log_y=False,
                        filename="./figures/" + experiment_name+"_progress.png")
```

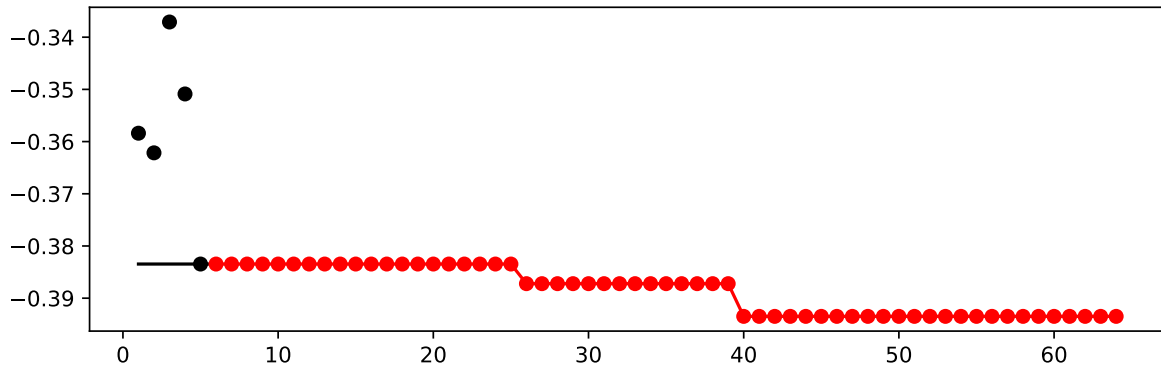


Figure 15.1: Progress plot. *Black* dots denote results from the initial design. *Red* dots illustrate the improvement found by the surrogate model based optimization.

- Print the results

```
print(gen_design_table(fun_control=fun_control,
                      spot=spot_tuner))
```

name	type	default	lower	upper	tuned	transform
C	float	1.0	0.1	10.0	5.064760042488824	None
kernel	factor	rbf	0.0	0.0	0.0	None
degree	int	3	3.0	3.0	3.0	None
gamma	factor	scale	0.0	1.0	1.0	None
coef0	float	0.0	0.0	0.0	0.0	None
shrinking	factor	0	0.0	1.0	0.0	None
probability	factor	0	1.0	1.0	1.0	None
tol	float	0.001	0.0001	0.01	0.009905536500848609	None
cache_size	float	200.0	100.0	400.0	136.5974675903489	None
break_ties	factor	0	0.0	1.0	1.0	None

15.10.1 Show variable importance

```
spot_tuner.plot_importance(threshold=0.025, filename="./figures/" + experiment_name+"_impo
```

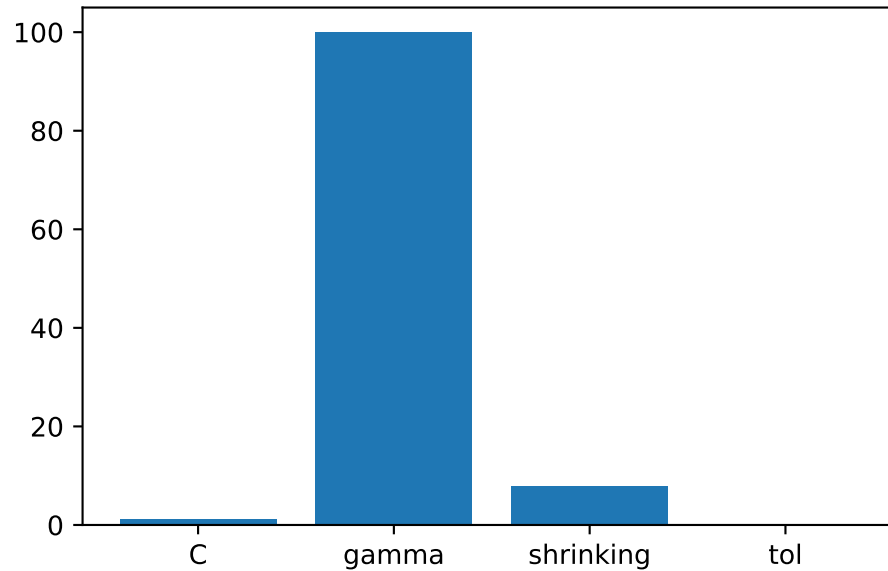


Figure 15.2: Variable importance plot, threshold 0.025.

15.10.2 Get Default Hyperparameters

```
from spotPython.hyperparameters.values import get_default_values, transform_hyper_parameter_values_default = get_default_values(fun_control) values_default = transform_hyper_parameter_values(fun_control=fun_control, hyper_parameter values_default
```

```
{'C': 1.0,  
'kernel': 'rbf',  
'degree': 3,  
'gamma': 'scale',  
'coef0': 0.0,  
'shrinking': 0,  
'probability': 0,  
'tol': 0.001,  
'cache_size': 200.0,
```

```
'break_ties': 0}
```

```
from sklearn.pipeline import make_pipeline
model_default = make_pipeline(fun_control["prep_model"], fun_control["core_model"](**value
model_default
```

```
Pipeline(steps=[('nonetype', None),
                  ('svc',
                   SVC(break_ties=0, cache_size=200.0, probability=0,
                       shrinking=0))])
```

i Note

- Default value for “probability” is False, but we need it to be True for the metric “mapk_score”.

```
values_default.update({"probability": 1})
```

15.10.3 Get SPOT Results

```
X = spot_tuner.to_all_dim(spot_tuner.min_X.reshape(1,-1))
print(X)
```

```
[[5.06476004e+00 0.00000000e+00 3.00000000e+00 1.00000000e+00
 0.00000000e+00 0.00000000e+00 1.00000000e+00 9.90553650e-03
 1.36597468e+02 1.00000000e+00]]
```

```
from spotPython.hyperparameters.values import assign_values, return_conf_list_from_var_dict
v_dict = assign_values(X, fun_control["var_name"])
return_conf_list_from_var_dict(var_dict=v_dict, fun_control=fun_control)
```

```
[{'C': 5.064760042488824,
  'kernel': 'rbf',
  'degree': 3,
  'gamma': 'auto',
  'coef0': 0.0,
```

```
'shrinking': 0,
'probability': 1,
'tol': 0.009905536500848609,
'cache_size': 136.5974675903489,
'break_ties': 1}]
```

```
from spotPython.hyperparameters.values import get_one_sklearn_model_from_X
model_spot = get_one_sklearn_model_from_X(X, fun_control)
model_spot
```

```
SVC(C=5.064760042488824, break_ties=1, cache_size=136.5974675903489,
    gamma='auto', probability=1, shrinking=0, tol=0.009905536500848609)
```

15.10.4 Evaluate SPOT Results

- Fetch the data.

```
from spotPython.utils.convert import get_Xy_from_df
X_train, y_train = get_Xy_from_df(fun_control["train"], fun_control["target_column"])
X_test, y_test = get_Xy_from_df(fun_control["test"], fun_control["target_column"])
X_test.shape, y_test.shape
```

```
((177, 64), (177,))
```

- Fit the model with the tuned hyperparameters. This gives one result:

```
model_spot.fit(X_train, y_train)
y_pred = model_spot.predict_proba(X_test)
res = mapk_score(y_true=y_test, y_pred=y_pred, k=3)
res
```

```
0.3691148775894538
```

```
def repeated_eval(n, model):
    res_values = []
    for i in range(n):
        model.fit(X_train, y_train)
        y_pred = model.predict_proba(X_test)
```



```

        res = mapk_score(y_true=y_test, y_pred=y_pred, k=3)
        res_values.append(res)
    mean_res = np.mean(res_values)
    print(f"mean_res: {mean_res}")
    std_res = np.std(res_values)
    print(f"std_res: {std_res}")
    min_res = np.min(res_values)
    print(f"min_res: {min_res}")
    max_res = np.max(res_values)
    print(f"max_res: {max_res}")
    median_res = np.median(res_values)
    print(f"median_res: {median_res}")
    return mean_res, std_res, min_res, max_res, median_res

```

15.10.5 Handling Non-deterministic Results

- Because the model is non-deterministic, we perform $n = 30$ runs and calculate the mean and standard deviation of the performance metric.

```

_ = repeated_eval(30, model_spot)

```

```

mean_res: 0.37046453232893917
std_res: 0.004799386985354715
min_res: 0.36252354048964214
max_res: 0.3804143126177025
median_res: 0.37052730696798486

```

15.10.6 Evaluation of the Default Hyperparameters

```

model_default["svc"].probability = True
model_default.fit(X_train, y_train)["svc"]

```

```

SVC(break_ties=0, cache_size=200.0, probability=True, shrinking=0)

```

- One evaluation of the default hyperparameters is performed on the hold-out test set.

```

y_pred = model_default.predict_proba(X_test)
mapk_score(y_true=y_test, y_pred=y_pred, k=3)

```

0.38888888888888884

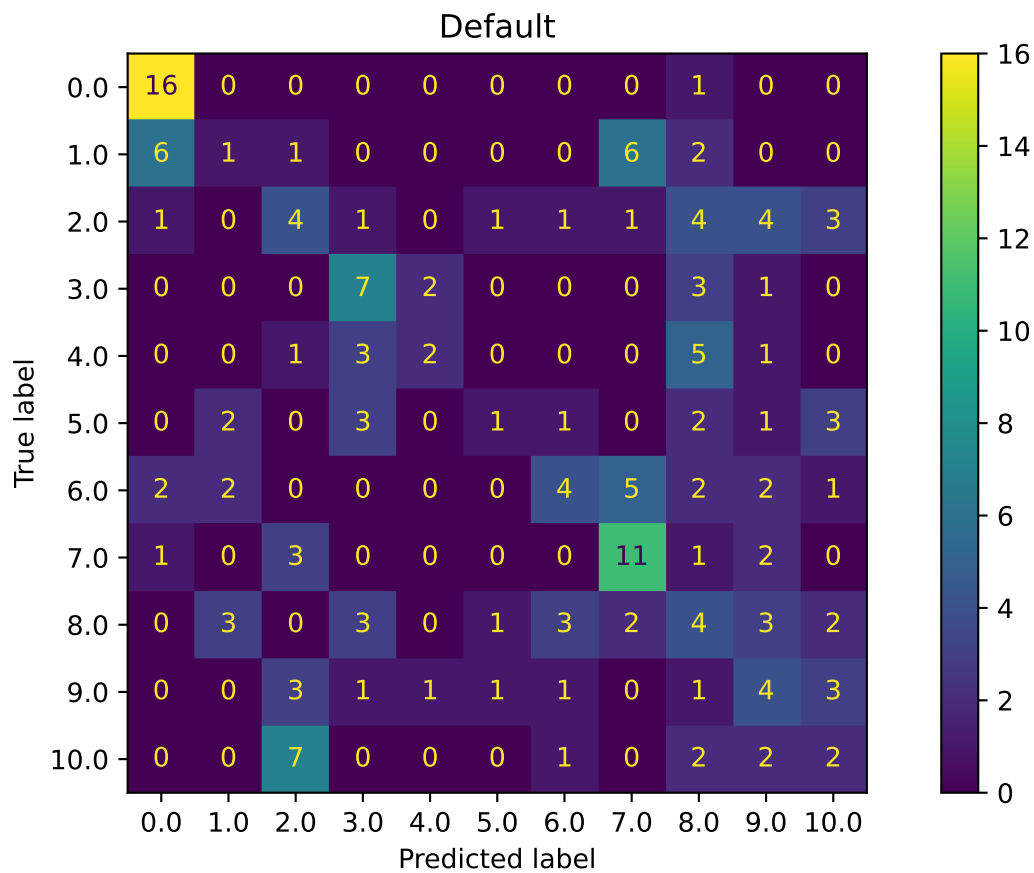
Since one single evaluation is not meaningful, we perform, similar to the evaluation of the SPOT results, $n = 30$ runs of the default setting and calculate the mean and standard deviation of the performance metric.

```
_ = repeated_eval(30, model_default)
```

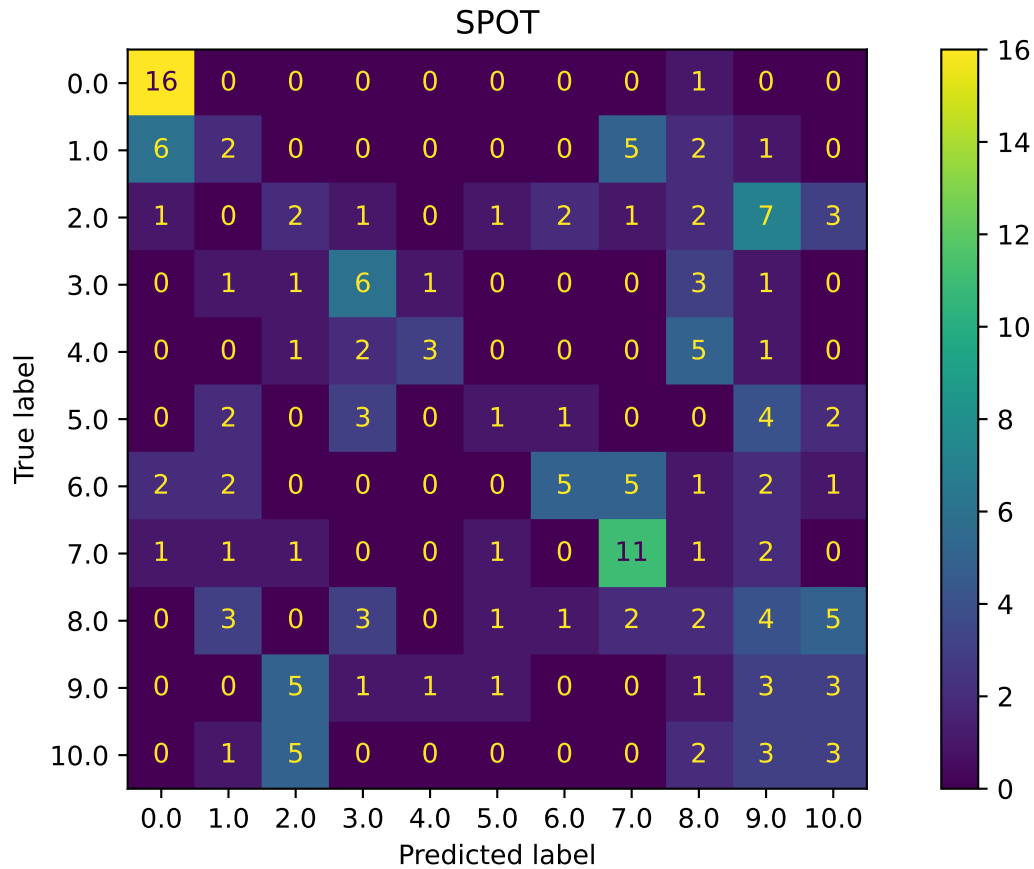
```
mean_res: 0.3848399246704331
std_res: 0.005316330033775537
min_res: 0.37476459510357824
max_res: 0.396421845574388
median_res: 0.3851224105461394
```

15.10.7 Plot: Compare Predictions

```
from spotPython.plot.validation import plot_confusion_matrix
plot_confusion_matrix(model_default, fun_control, title = "Default")
```



```
plot_confusion_matrix(model_spot, fun_control, title="SPOT")
```



```
min(spot_tuner.y), max(spot_tuner.y)
```

```
(-0.39348370927318294, -0.33583959899749366)
```

15.10.8 Cross-validated Evaluations

```
from spotPython.sklearn.traintest import evaluate_cv
fun_control.update({
    "eval": "train_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)
```

```
(0.34968553459119495, None)
```

```

fun_control.update({
    "eval": "test_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)

```

(0.37461873638344223, None)

- This is the evaluation that will be used in the comparison:

```

fun_control.update({
    "eval": "data_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)

```

(0.3605633802816901, None)

15.10.9 Detailed Hyperparameter Plots

```

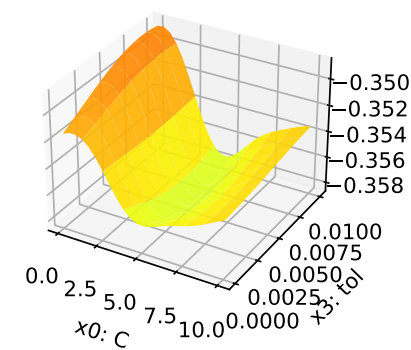
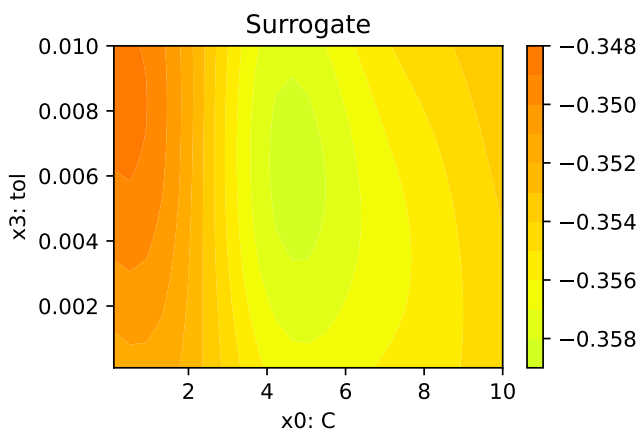
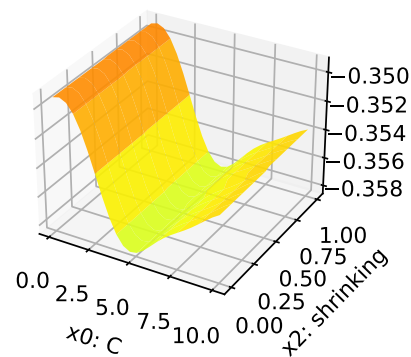
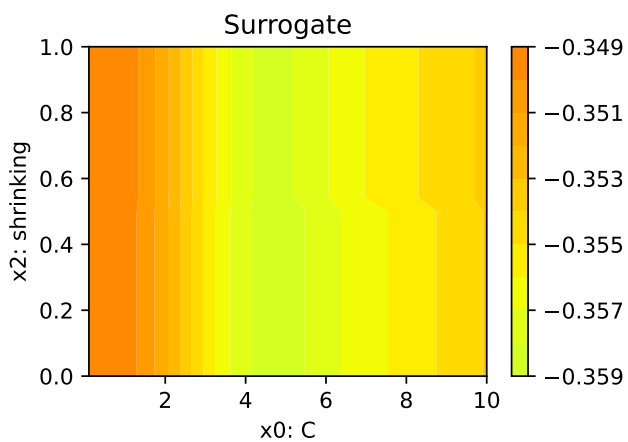
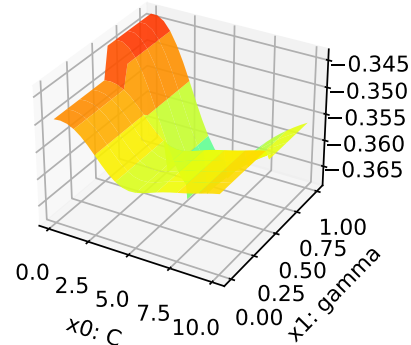
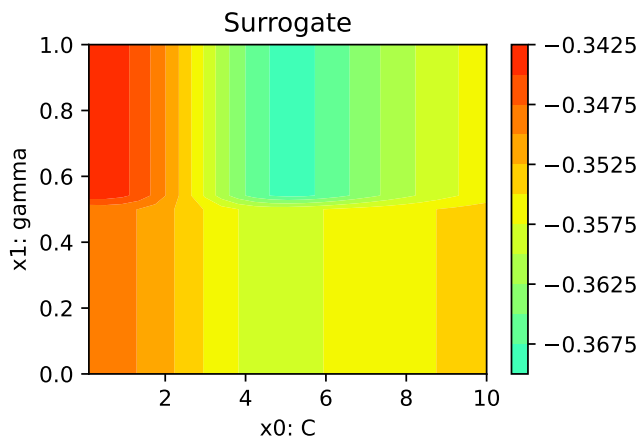
filename = "./figures/" + experiment_name
spot_tuner.plot_important_hyperparameter_contour(filename=filename)

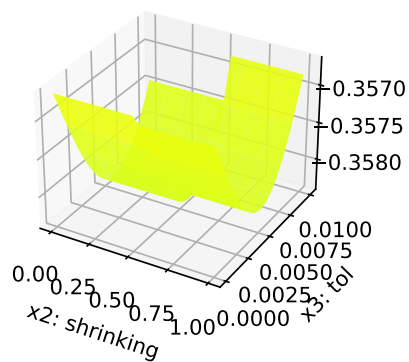
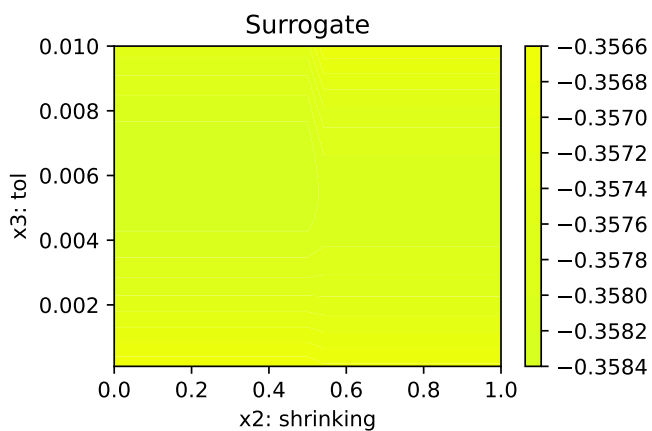
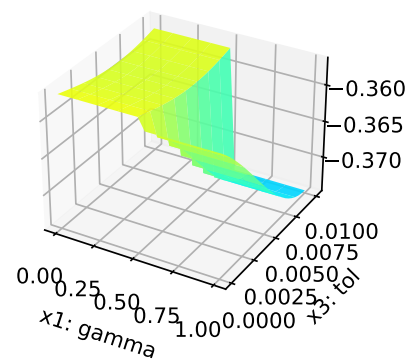
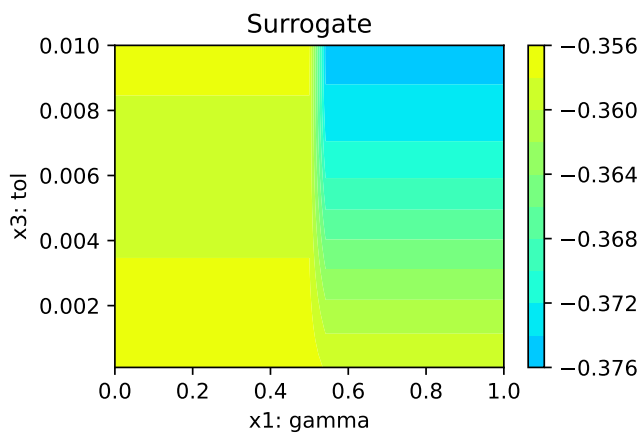
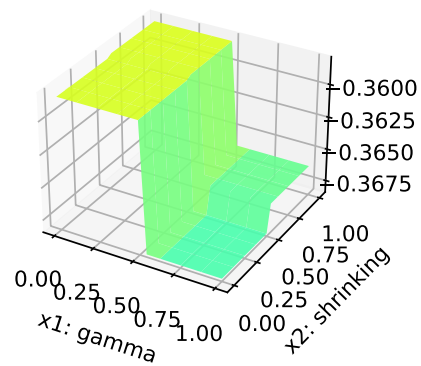
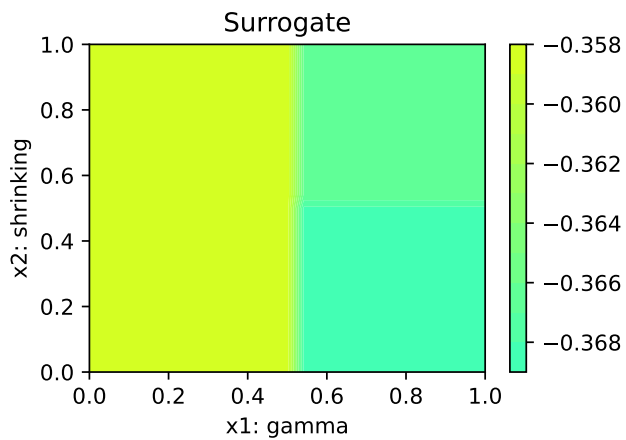
```

```

C: 1.1752619190262712
gamma: 100.0
shrinking: 7.814829945476416
tol: 0.09592199120674225

```





15.10.10 Parallel Coordinates Plot

```
spot_tuner.parallel_plot()
```

Unable to display output for mime type(s): text/html

Unable to display output for mime type(s): text/html

15.10.11 Plot all Combinations of Hyperparameters

- Warning: this may take a while.

```
PLOT_ALL = False
if PLOT_ALL:
    n = spot_tuner.k
    for i in range(n-1):
        for j in range(i+1, n):
            spot_tuner.plot_contour(i=i, j=j, min_z=min_z, max_z = max_z)
```


16 HPT: sklearn KNN Classifier VBDP Data

spotPython can be installed via pip. Alternatively, the source code can be downloaded from gitHub: <https://github.com/sequential-parameter-optimization/spotPython>.

```
!pip install spotPython
```

- Uncomment the following lines if you want to for (re-)installation the latest version of spotPython from gitHub.

```
# import sys
# !{sys.executable} -m pip install --upgrade build
# !{sys.executable} -m pip install --upgrade --force-reinstall spotPython
```

16.1 Step 1: Setup

Before we consider the detailed experimental setup, we select the parameters that affect run time and the initial design size.

```
MAX_TIME = 1
INIT_SIZE = 5
ORIGINAL = False
PREFIX = "19"

import warnings
warnings.filterwarnings("ignore")
```

16.2 Step 2: Initialization of the Empty fun_control Dictionary

```
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_experiment_name, get_spot_tensorboard_path
from spotPython.utils.device import getDevice

experiment_name = get_experiment_name(prefix=PREFIX)

fun_control = fun_control_init(
    task="classification",
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name))
```

16.2.1 Load Data: Classification VBDP

```
import pandas as pd
if ORIGINAL == True:
    train_df = pd.read_csv('./data/VBDP/trainn.csv')
    test_df = pd.read_csv('./data/VBDP/testt.csv')
else:
    train_df = pd.read_csv('./data/VBDP/train.csv')
    # remove the id column
    train_df = train_df.drop(columns=['id'])

from sklearn.preprocessing import OrdinalEncoder
n_samples = train_df.shape[0]
n_features = train_df.shape[1] - 1
target_column = "prognosis"
# Encoder our prognosis labels as integers for easier decoding later
enc = OrdinalEncoder()
train_df[target_column] = enc.fit_transform(train_df[[target_column]])
train_df.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
print(train_df.shape)
train_df.head()
```

(707, 65)

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19
0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	1.0
1	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0
2	0.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0
3	0.0	0.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	1.0	1.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The full data set `train_df` 64 features. The target column is labeled as `prognosis`.

16.2.2 Holdout Train and Test Data

We split out a hold-out test set (25% of the data) so we can calculate an example MAP@K

```
import numpy as np
from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = train_test_split(train_df.drop(target_column, axis=1),
                                                    random_state=42,
                                                    test_size=0.25,
                                                    stratify=train_df[target_column])
train = pd.DataFrame(np.hstack((X_train, np.array(y_train).reshape(-1, 1))))
test = pd.DataFrame(np.hstack((X_test, np.array(y_test).reshape(-1, 1))))
train.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
test.columns = [f"x{i}" for i in range(1, n_features+1)] + [target_column]
print(train.shape)
print(test.shape)
train.head()
```

(530, 65)

(177, 65)

	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19
0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0
2	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0
4	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0

```
# add the dataset to the fun_control
fun_control.update({"data": train_df, # full dataset,
                  "train": train,
```

```

        "test": test,
        "n_samples": n_samples,
        "target_column": target_column})

```

16.3 Step 4: Specification of the Preprocessing Model

Data preprocessing can be very simple, e.g., you can ignore it. Then you would choose the `prep_model` "None":

```

prep_model = None
fun_control.update({"prep_model": prep_model})

```

A default approach for numerical data is the `StandardScaler` (mean 0, variance 1). This can be selected as follows:

```

# prep_model = StandardScaler()
# fun_control.update({"prep_model": prep_model})

```

Even more complicated pre-processing steps are possible, e.g., the following pipeline:

```

# categorical_columns = []
# one_hot_encoder = OneHotEncoder(handle_unknown="ignore", sparse_output=False)
# prep_model = ColumnTransformer(
#     transformers=[
#         ("categorical", one_hot_encoder, categorical_columns),
#     ],
#     remainder=StandardScaler(),
# )

```

16.4 Step 5: Select Model (algorithm) and `core_model_hyper_dict`

The selection of the algorithm (ML model) that should be tuned is done by specifying the its name from the `sklearn` implementation. For example, the `SVC` support vector machine classifier is selected as follows:

```

add_core_model_to_fun_control(SVC, fun_control, SklearnHyperDict)

```

Other `core_models` are, e.g.,:

- RidgeCV
- GradientBoostingRegressor
- ElasticNet
- RandomForestClassifier
- LogisticRegression
- KNeighborsClassifier
- RandomForestClassifier
- GradientBoostingClassifier
- HistGradientBoostingClassifier

We will use the `RandomForestClassifier` classifier in this example.

```
from sklearn.linear_model import RidgeCV
from sklearn.ensemble import RandomForestClassifier
from sklearn.svm import SVC
from sklearn.linear_model import LogisticRegression
from sklearn.neighbors import KNeighborsClassifier
from sklearn.ensemble import GradientBoostingClassifier
from sklearn.ensemble import GradientBoostingRegressor
from sklearn.ensemble import HistGradientBoostingClassifier
from sklearn.linear_model import ElasticNet
from spotPython.hyperparameters.values import add_core_model_to_fun_control
from spotPython.data.sklearn_hyper_dict import SklearnHyperDict
from spotPython.fun.hypersklearn import HyperSklearn

# core_model = RidgeCV
# core_model = GradientBoostingRegressor
# core_model = ElasticNet
# core_model = RandomForestClassifier
core_model = KNeighborsClassifier
# core_model = LogisticRegression
# core_model = KNeighborsClassifier
# core_model = GradientBoostingClassifier
# core_model = HistGradientBoostingClassifier
add_core_model_to_fun_control(core_model=core_model,
                             fun_control=fun_control,
                             hyper_dict=SklearnHyperDict,
                             filename=None)
```

Now `fun_control` has the information from the JSON file. The available hyperparameters are:

```
print(*fun_control["core_model_hyper_dict"].keys(), sep="\n")
```

```
n_neighbors
weights
algorithm
leaf_size
p
```

16.5 Step 6: Modify hyper_dict Hyperparameters for the Selected Algorithm aka core_model

16.5.1 Modify hyperparameter of type numeric and integer (boolean)

Numeric and boolean values can be modified using the `modify_hyper_parameter_bounds` method. For example, to change the `tol` hyperparameter of the SVC model to the interval `[1e-3, 1e-2]`, the following code can be used:

```
modify_hyper_parameter_bounds(fun_control, "tol", bounds=[1e-3, 1e-2])
```

```
# from spotPython.hyperparameters.values import modify_hyper_parameter_bounds
# modify_hyper_parameter_bounds(fun_control, "probability", bounds=[1, 1])
```

16.5.2 Modify hyperparameter of type factor

`spotPython` provides functions for modifying the hyperparameters, their bounds and factors as well as for activating and de-activating hyperparameters without re-compilation of the Python source code. These functions were described in [Section 12.6](#).

Factors can be modified with the `modify_hyper_parameter_levels` function. For example, to exclude the `sigmoid` kernel from the tuning, the `kernel` hyperparameter of the SVC model can be modified as follows:

```
modify_hyper_parameter_levels(fun_control, "kernel", ["linear", "rbf"])
```

The new setting can be controlled via:

```
fun_control["core_model_hyper_dict"]["kernel"]
```

```
# from spotPython.hyperparameters.values import modify_hyper_parameter_levels
# modify_hyper_parameter_levels(fun_control, "kernel", ["rbf"])
```

16.5.3 Optimizers

Optimizers are described in Section [12.6.1](#).

16.5.4 Selection of the Objective: Metric and Loss Functions

- Machine learning models are optimized with respect to a metric, for example, the `accuracy` function.
- Deep learning, e.g., neural networks are optimized with respect to a loss function, for example, the `cross_entropy` function and evaluated with respect to a metric, for example, the `accuracy` function.

16.6 Step 7: Selection of the Objective (Loss) Function

The loss function, that is usually used in deep learning for optimizing the weights of the net, is stored in the `fun_control` dictionary as `"loss_function"`.

16.6.1 Metric Function

There are two different types of metrics in `spotPython`:

1. `"metric_river"` is used for the river based evaluation via `eval_oml_iter_progressive`.
2. `"metric_sklearn"` is used for the sklearn based evaluation.

We will consider multi-class classification metrics, e.g., `mapk_score` and `top_k_accuracy_score`.

Predict Probabilities

In this multi-class classification example the machine learning algorithm should return the probabilities of the specific classes (`"predict_proba"`) instead of the predicted values.

We set `"predict_proba"` to `True` in the `fun_control` dictionary.

16.6.1.1 The MAPK Metric

To select the MAPK metric, the following two entries can be added to the `fun_control` dictionary:

```
"metric_sklearn": mapk_score"
```

```
"metric_params": {"k": 3}.
```

16.6.1.2 Other Metrics

Alternatively, other metrics for multi-class classification can be used, e.g.,: `* top_k_accuracy_score` or `* roc_auc_score`

The metric `roc_auc_score` requires the parameter `"multi_class"`, e.g.,

```
"multi_class": "ovr".
```

This is set in the `fun_control` dictionary.

Weights

`spotPython` performs a minimization, therefore, metrics that should be maximized have to be multiplied by -1. This is done by setting `"weights"` to -1.

- The complete setup for the metric in our example is:

```
from spotPython.utils.metrics import mapk_score
fun_control.update({
    "weights": -1,
    "metric_sklearn": mapk_score,
    "predict_proba": True,
    "metric_params": {"k": 3},
})
```

16.6.2 Evaluation on Hold-out Data

- The default method for computing the performance is `"eval_holdout"`.
- Alternatively, cross-validation can be used for every machine learning model.
- Specifically for `RandomForests`, the OOB-score can be used.

```
fun_control.update({
    "eval": "train_hold_out",
})
```

16.6.2.1 Cross Validation

Instead of using the OOB-score, the classical cross validation can be used. The number of folds is set by the key `"k_folds"`. For example, to use 5-fold cross validation, the key `"k_folds"` is set to 5. Uncomment the following line to use cross validation:


```
# fun_control.update({
#     "eval": "train_cv",
#     "k_folds": 10,
# })
```

16.7 Step 8: Calling the SPOT Function

16.7.1 Preparing the SPOT Call

- Get types and variable names as well as lower and upper bounds for the hyperparameters.

```
# extract the variable types, names, and bounds
from spotPython.hyperparameters.values import (get_bound_values,
        get_var_name,
        get_var_type,)
var_type = get_var_type(fun_control)
var_name = get_var_name(fun_control)
lower = get_bound_values(fun_control, "lower")
upper = get_bound_values(fun_control, "upper")
```

```
from spotPython.utils.eda import gen_design_table
print(gen_design_table(fun_control))
```

name	type	default	lower	upper	transform
n_neighbors	int	2	1	7	transform_power_2_int
weights	factor	uniform	0	1	None
algorithm	factor	auto	0	3	None
leaf_size	int	5	2	7	transform_power_2_int
p	int	2	1	2	None

16.7.2 The Objective Function

The objective function is selected next. It implements an interface from `sklearn`'s training, validation, and testing methods to `spotPython`.

```
from spotPython.fun.hypersklearn import HyperSklearn
fun = HyperSklearn().fun_sklearn
```

16.7.3 Run the Spot Optimizer

- Run SPOT for approx. x mins (`max_time`).
- Note: the run takes longer, because the evaluation time of initial design (here: `init_size`, 20 points) is not considered.

```
from spotPython.hyperparameters.values import get_default_hyperparameters_as_array
X_start = get_default_hyperparameters_as_array(fun_control)
X_start
```

```
array([[2, 0, 0, 5, 2]])
```

```
import numpy as np
from spotPython.spot import spot
from math import inf
spot_tuner = spot.Spot(fun=fun,
                       lower = lower,
                       upper = upper,
                       fun_evals = inf,
                       fun_repeats = 1,
                       max_time = MAX_TIME,
                       noise = False,
                       tolerance_x = np.sqrt(np.spacing(1)),
                       var_type = var_type,
                       var_name = var_name,
                       infill_criterion = "y",
                       n_points = 1,
                       seed=123,
                       log_level = 50,
                       show_models= False,
                       show_progress= True,
                       fun_control = fun_control,
                       design_control={"init_size": INIT_SIZE,
                                      "repeats": 1},
                       surrogate_control={"noise": True,
                                         "cod_type": "norm",
                                         "min_theta": -4,
                                         "max_theta": 3,
                                         "n_theta": len(var_name),
                                         "model_fun_evals": 10_000,
                                         "log_level": 50})
```

```
spot_tuner.run(X_start=X_start)
})
```

```
spotPython tuning: -0.3107769423558897 [-----] 0.27%
spotPython tuning: -0.3107769423558897 [-----] 0.57%
spotPython tuning: -0.3107769423558897 [-----] 0.84%
spotPython tuning: -0.3107769423558897 [-----] 1.14%
spotPython tuning: -0.3107769423558897 [-----] 1.55%
spotPython tuning: -0.3107769423558897 [-----] 2.04%
spotPython tuning: -0.3107769423558897 [-----] 2.68%
spotPython tuning: -0.3107769423558897 [-----] 3.26%
spotPython tuning: -0.3107769423558897 [-----] 3.73%
spotPython tuning: -0.3107769423558897 [-----] 4.29%
spotPython tuning: -0.3107769423558897 [-----] 4.70%
spotPython tuning: -0.3107769423558897 [#-----] 6.00%
spotPython tuning: -0.3107769423558897 [#-----] 7.86%
spotPython tuning: -0.3107769423558897 [#-----] 9.10%
spotPython tuning: -0.3107769423558897 [#-----] 10.48%
spotPython tuning: -0.3107769423558897 [#-----] 11.63%
spotPython tuning: -0.3107769423558897 [#-----] 13.17%
```

spotPython tuning: -0.3107769423558897 [#-----] 14.08%

spotPython tuning: -0.3107769423558897 [##-----] 15.14%

spotPython tuning: -0.3107769423558897 [##-----] 16.95%

spotPython tuning: -0.3107769423558897 [##-----] 17.82%

spotPython tuning: -0.3107769423558897 [##-----] 18.69%

spotPython tuning: -0.3107769423558897 [##-----] 19.55%

spotPython tuning: -0.3107769423558897 [##-----] 21.08%

spotPython tuning: -0.3107769423558897 [##-----] 22.07%

spotPython tuning: -0.3107769423558897 [##-----] 23.56%

spotPython tuning: -0.3107769423558897 [##-----] 24.59%

spotPython tuning: -0.3107769423558897 [###-----] 26.59%

spotPython tuning: -0.3107769423558897 [###-----] 27.71%

spotPython tuning: -0.3107769423558897 [###-----] 29.46%

spotPython tuning: -0.3107769423558897 [###-----] 30.60%

spotPython tuning: -0.3107769423558897 [###-----] 31.93%

spotPython tuning: -0.3107769423558897 [###-----] 33.11%

spotPython tuning: -0.3107769423558897 [####-----] 35.83%

spotPython tuning: -0.3107769423558897 [####-----] 38.16%

spotPython tuning: -0.3107769423558897 [####-----] 39.71%

```

spotPython tuning: -0.3107769423558897 [####-----] 41.33%

spotPython tuning: -0.3107769423558897 [####-----] 43.09%

spotPython tuning: -0.3107769423558897 [#####-----] 46.19%

spotPython tuning: -0.3107769423558897 [#####-----] 47.94%

spotPython tuning: -0.3107769423558897 [#####-----] 49.98%

spotPython tuning: -0.3107769423558897 [#####-----] 51.89%

spotPython tuning: -0.3107769423558897 [#####-----] 54.83%

spotPython tuning: -0.3107769423558897 [#####-----] 56.53%

spotPython tuning: -0.3107769423558897 [#####-----] 58.45%

spotPython tuning: -0.3107769423558897 [#####-----] 61.12%

spotPython tuning: -0.3107769423558897 [#####-----] 65.06%

spotPython tuning: -0.3107769423558897 [#####-----] 67.13%

spotPython tuning: -0.3107769423558897 [#####-----] 69.48%

spotPython tuning: -0.3107769423558897 [#####-----] 72.40%

spotPython tuning: -0.3107769423558897 [#####-----] 85.81%

spotPython tuning: -0.3157894736842105 [#####] 99.99%

spotPython tuning: -0.3157894736842105 [#####] 100.00% Done...

<spotPython.spot.spot.Spot at 0x2bb693b50>

```

16.8 Step 9: Tensorboard

The textual output shown in the console (or code cell) can be visualized with Tensorboard as described in Section 12.9, see also the description in the documentation: [Tensorboard](#).

16.9 Step 10: Results

After the hyperparameter tuning run is finished, the progress of the hyperparameter tuning can be visualized. The following code generates the progress plot from `?@fig-progress`.

```
spot_tuner.plot_progress(log_y=False,
                        filename="./figures/" + experiment_name+"_progress.png")
```

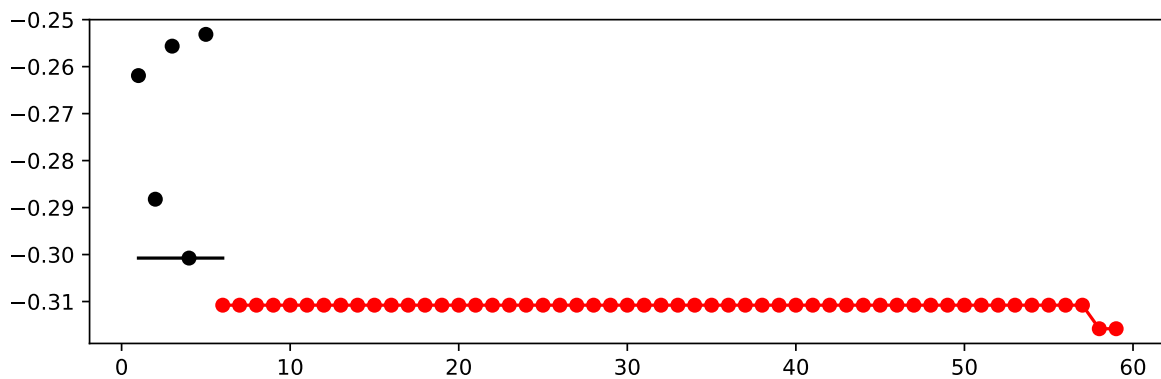


Figure 16.1: Progress plot. *Black* dots denote results from the initial design. *Red* dots illustrate the improvement found by the surrogate model based optimization.

- Print the results

```
print(gen_design_table(fun_control=fun_control,
                      spot=spot_tuner))
```

name	type	default	lower	upper	tuned	transform
n_neighbors	int	2	1	7	4.0	transform_power_2_int
weights	factor	uniform	0	1	1.0	None
algorithm	factor	auto	0	3	1.0	None
leaf_size	int	5	2	7	6.0	transform_power_2_int
p	int	2	1	2	1.0	None

16.9.1 Show variable importance

```
spot_tuner.plot_importance(threshold=0.025, filename="./figures/" + experiment_name+"_impo
```

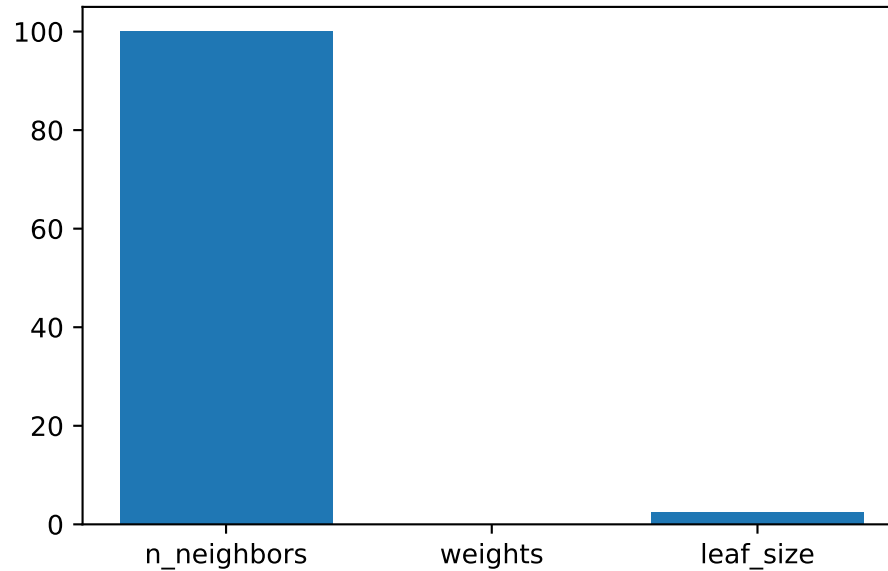


Figure 16.2: Variable importance plot, threshold 0.025.

16.9.2 Get Default Hyperparameters

```
from spotPython.hyperparameters.values import get_default_values, transform_hyper_parameter_values_default = get_default_values(fun_control)
values_default = transform_hyper_parameter_values(fun_control=fun_control, hyper_parameter_values_default
```

```
{'n_neighbors': 4,
 'weights': 'uniform',
 'algorithm': 'auto',
 'leaf_size': 32,
 'p': 2}
```

```
from sklearn.pipeline import make_pipeline
model_default = make_pipeline(fun_control["prep_model"], fun_control["core_model"](**value
```

```
model_default
```

```
Pipeline(steps=[('nonetype', None),  
                 ('kneighborsclassifier',  
                  KNeighborsClassifier(leaf_size=32, n_neighbors=4))])
```

16.9.3 Get SPOT Results

```
X = spot_tuner.to_all_dim(spot_tuner.min_X.reshape(1,-1))  
print(X)
```

```
[[4. 1. 1. 6. 1.]]
```

```
from spotPython.hyperparameters.values import assign_values, return_conf_list_from_var_dict  
v_dict = assign_values(X, fun_control["var_name"])  
return_conf_list_from_var_dict(var_dict=v_dict, fun_control=fun_control)
```

```
[{'n_neighbors': 16,  
  'weights': 'distance',  
  'algorithm': 'ball_tree',  
  'leaf_size': 64,  
  'p': 1}]
```

```
from spotPython.hyperparameters.values import get_one_sklearn_model_from_X  
model_spot = get_one_sklearn_model_from_X(X, fun_control)  
model_spot
```

```
KNeighborsClassifier(algorithm='ball_tree', leaf_size=64, n_neighbors=16, p=1,  
                    weights='distance')
```

16.9.4 Evaluate SPOT Results

- Fetch the data.

```
from spotPython.utils.convert import get_Xy_from_df  
X_train, y_train = get_Xy_from_df(fun_control["train"], fun_control["target_column"])
```



```
X_test, y_test = get_Xy_from_df(fun_control["test"], fun_control["target_column"])
X_test.shape, y_test.shape
```

```
((177, 64), (177,))
```

- Fit the model with the tuned hyperparameters. This gives one result:

```
model_spot.fit(X_train, y_train)
y_pred = model_spot.predict_proba(X_test)
res = mapk_score(y_true=y_test, y_pred=y_pred, k=3)
res
```

```
0.30979284369114873
```

```
def repeated_eval(n, model):
    res_values = []
    for i in range(n):
        model.fit(X_train, y_train)
        y_pred = model.predict_proba(X_test)
        res = mapk_score(y_true=y_test, y_pred=y_pred, k=3)
        res_values.append(res)
    mean_res = np.mean(res_values)
    print(f"mean_res: {mean_res}")
    std_res = np.std(res_values)
    print(f"std_res: {std_res}")
    min_res = np.min(res_values)
    print(f"min_res: {min_res}")
    max_res = np.max(res_values)
    print(f"max_res: {max_res}")
    median_res = np.median(res_values)
    print(f"median_res: {median_res}")
    return mean_res, std_res, min_res, max_res, median_res
```

16.9.5 Handling Non-deterministic Results

- Because the model is non-deterministic, we perform $n = 30$ runs and calculate the mean and standard deviation of the performance metric.

```
_ = repeated_eval(30, model_spot)
```

```
mean_res: 0.30979284369114873
std_res: 0.0
min_res: 0.30979284369114873
max_res: 0.30979284369114873
median_res: 0.30979284369114873
```

16.9.6 Evaluation of the Default Hyperparameters

```
model_default.fit(X_train, y_train)["kneighborsclassifier"]
```

```
KNeighborsClassifier(leaf_size=32, n_neighbors=4)
```

- One evaluation of the default hyperparameters is performed on the hold-out test set.

```
y_pred = model_default.predict_proba(X_test)
mapk_score(y_true=y_test, y_pred=y_pred, k=3)
```

```
0.2768361581920904
```

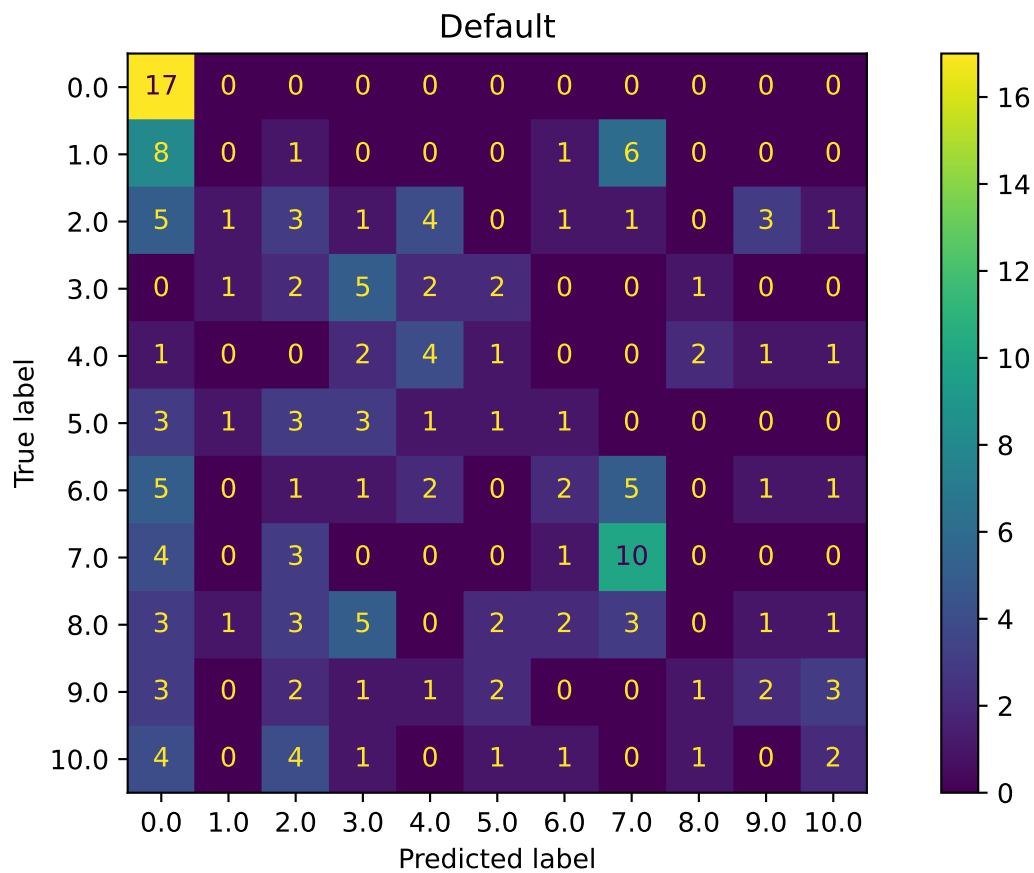
Since one single evaluation is not meaningful, we perform, similar to the evaluation of the SPOT results, $n = 30$ runs of the default setting and calculate the mean and standard deviation of the performance metric.

```
_ = repeated_eval(30, model_default)
```

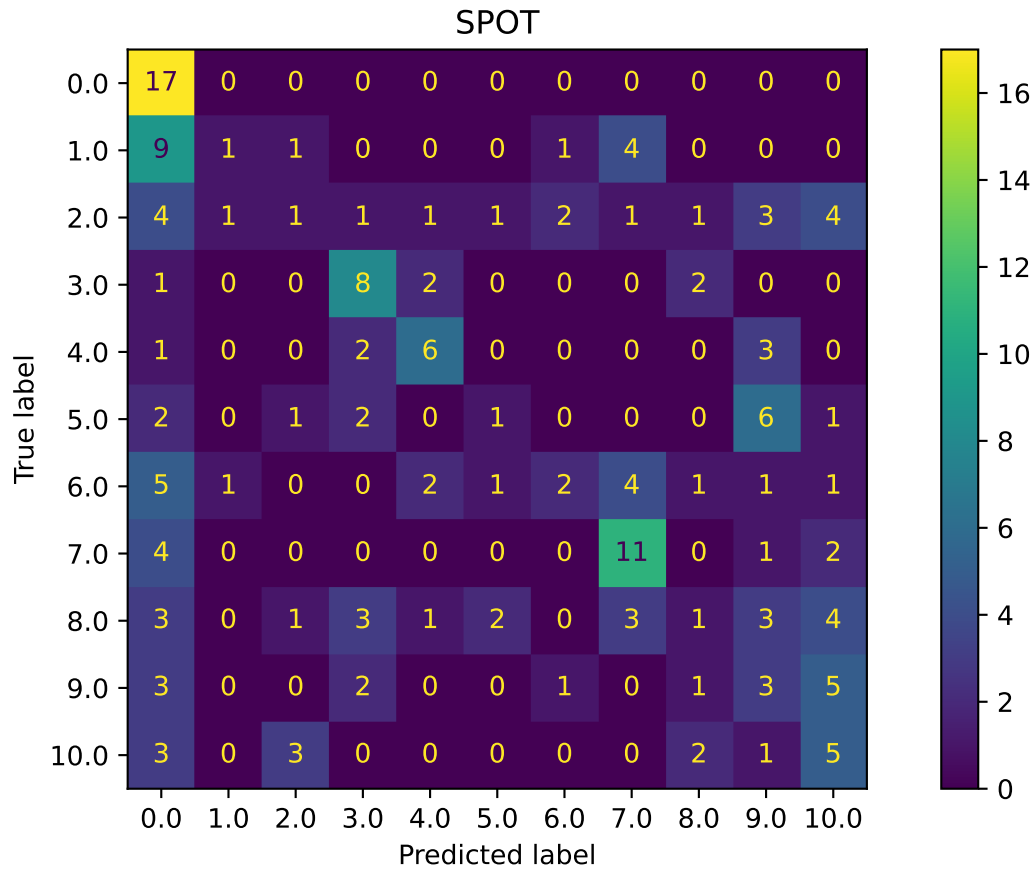
```
mean_res: 0.2768361581920903
std_res: 1.1102230246251565e-16
min_res: 0.2768361581920904
max_res: 0.2768361581920904
median_res: 0.2768361581920904
```

16.9.7 Plot: Compare Predictions

```
from spotPython.plot.validation import plot_confusion_matrix
plot_confusion_matrix(model_default, fun_control, title = "Default")
```



```
plot_confusion_matrix(model_spot, fun_control, title="SPOT")
```



```
min(spot_tuner.y), max(spot_tuner.y)
```

```
(-0.3157894736842105, -0.23558897243107768)
```

16.9.8 Cross-validated Evaluations

```
from spotPython.sklearn.traintest import evaluate_cv
fun_control.update({
    "eval": "train_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)
```

```
(0.3128930817610063, None)
```

```

fun_control.update({
    "eval": "test_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)

```

(0.2832788671023965, None)

- This is the evaluation that will be used in the comparison:

```

fun_control.update({
    "eval": "data_cv",
    "k_folds": 10,
})
evaluate_cv(model=model_spot, fun_control=fun_control, verbose=0)

```

(0.31310529845741114, None)

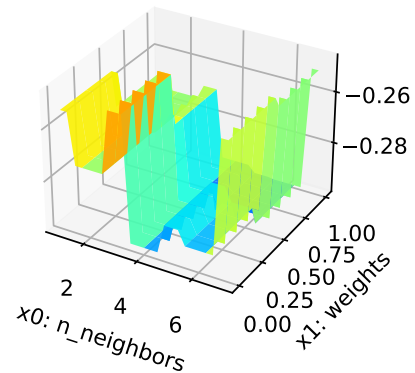
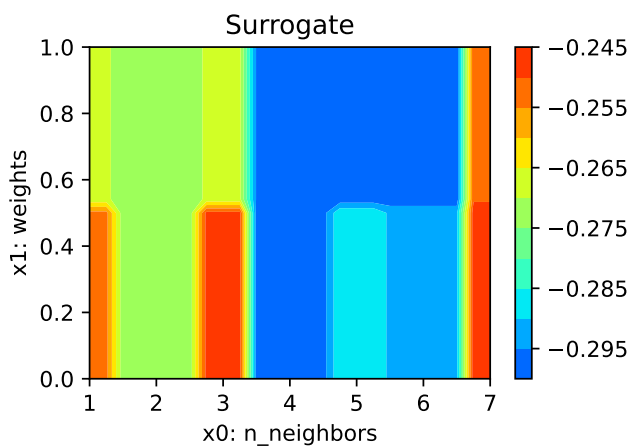
16.9.9 Detailed Hyperparameter Plots

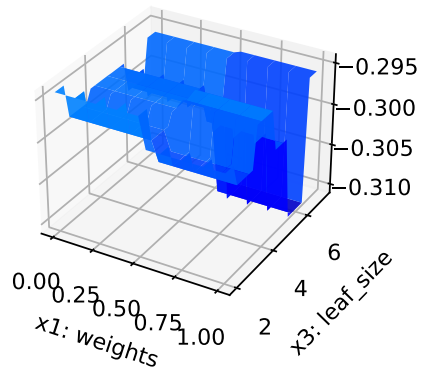
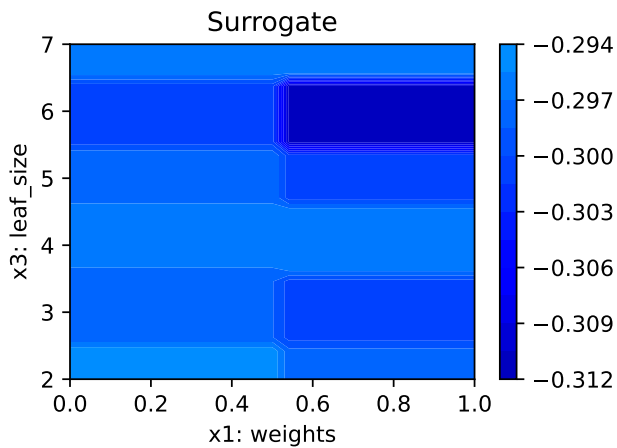
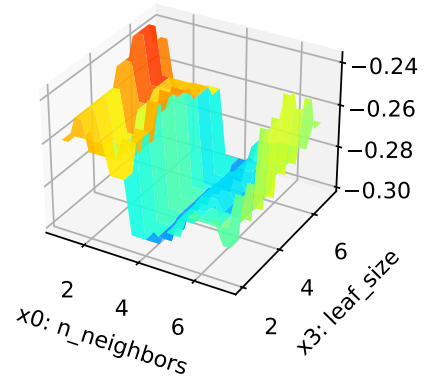
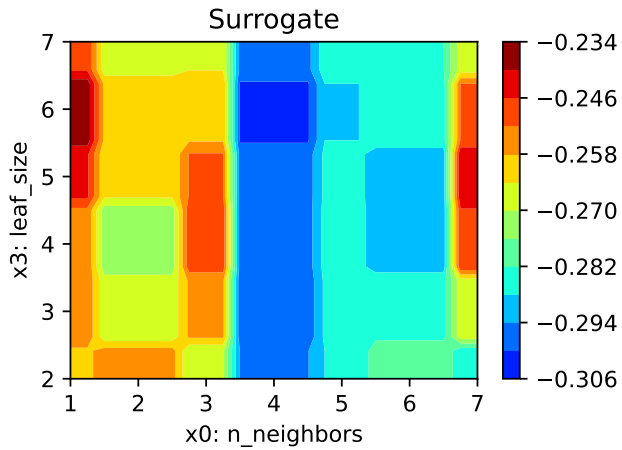
```

filename = "./figures/" + experiment_name
spot_tuner.plot_important_hyperparameter_contour(filename=filename)

```

n_neighbors: 100.0
weights: 0.03921716445201348
leaf_size: 2.5745968223080262





16.9.10 Parallel Coordinates Plot

```
spot_tuner.parallel_plot()
```

Unable to display output for mime type(s): text/html

Unable to display output for mime type(s): text/html


16.9.11 Plot all Combinations of Hyperparameters

- Warning: this may take a while.

```
PLOT_ALL = False
if PLOT_ALL:
    n = spot_tuner.k
    for i in range(n-1):
        for j in range(i+1, n):
            spot_tuner.plot_contour(i=i, j=j, min_z=min_z, max_z = max_z)
```

17 HPT PyTorch Lightning: VBDP

In this tutorial, we will show how `spotPython` can be integrated into the PyTorch Lightning training workflow for a classification task.

 Caution: Data must be downloaded manually

- Ensure that the corresponding data is available as `./data/VBDP/train.csv`.

This document refers to the latest `spotPython` version, which can be installed via `pip`. Alternatively, the source code can be downloaded from `gitHub`: <https://github.com/sequential-parameter-optimization/spotPython>.

- Uncomment the following lines if you want to for (re-)installation the latest version of `spotPython` from `GitHub`.

```
# import sys
# !{sys.executable} -m pip install --upgrade build
# !{sys.executable} -m pip install --upgrade --force-reinstall spotPython
```

17.1 Step 1: Setup

- Before we consider the detailed experimental setup, we select the parameters that affect run time, initial design size, etc.
- The parameter `MAX_TIME` specifies the maximum run time in seconds.
- The parameter `INIT_SIZE` specifies the initial design size.
- The parameter `WORKERS` specifies the number of workers.
- The prefix `PREFIX` is used for the experiment name and the name of the log file.

```
MAX_TIME = 1
INIT_SIZE = 5
WORKERS = 0
PREFIX="31"
```


 **Caution:** Run time and initial design size should be increased for real experiments

- `MAX_TIME` is set to one minute for demonstration purposes. For real experiments, this should be increased to at least 1 hour.
- `INIT_SIZE` is set to 5 for demonstration purposes. For real experiments, this should be increased to at least 10.
- `WORKERS` is set to 0 for demonstration purposes. For real experiments, this should be increased. See the warnings that are printed when the number of workers is set to 0.

 **Note:** Device selection

- Although there are no `.cuda()` or `.to(device)` calls required, because Lightning does these for you, see [LIGHTNINGMODULE](#), we would like to know which device is used. Therefore, we imitate the LightningModule behaviour which selects the highest device.
- The method `spotPython.utils.device.getDevice()` returns the device that is used by Lightning.

17.2 Step 2: Initialization of the `fun_control` Dictionary

`spotPython` uses a Python dictionary for storing the information required for the hyperparameter tuning process, which was described in Section 12.2, see [Initialization of the `fun_control` Dictionary](#) in the documentation.

```
from spotPython.utils.init import fun_control_init
from spotPython.utils.file import get_experiment_name, get_spot_tensorboard_path
from spotPython.utils.device import getDevice

experiment_name = get_experiment_name(prefix=PREFIX)
fun_control = fun_control_init(
    spot_tensorboard_path=get_spot_tensorboard_path(experiment_name),
    num_workers=WORKERS,
    device=getDevice(),
    _L_in=64,
    _L_out=11)

fun_control["device"]
```

'mps'

17.3 Step 3: PyTorch Data Loading

17.3.1 Lightning Dataset and DataModule

The data loading and preprocessing is handled by `Lightning` and `PyTorch`. It comprehends the following classes:

- `CSVDataset`: A class that loads the data from a CSV file. [\[SOURCE\]](#)
- `CSVDataModule`: A class that prepares the data for training and testing. [\[SOURCE\]](#)

Section [17.12.2](#) illustrates how to access the data.

17.4 Step 4: Preprocessing

Preprocessing is handled by `Lightning` and `PyTorch`. It can be implemented in the `CSVDataModule` class [\[SOURCE\]](#) and is described in the [LIGHTNINGDATAMODULE](#) documentation. Here you can find information about the `transforms` methods.

17.5 Step 5: Select the NN Model (algorithm) and core_model_hyper_dict

`spotPython` includes the `NetLightBase` class [\[SOURCE\]](#) for configurable neural networks. The class is imported here. It inherits from the class `Lightning.LightningModule`, which is the base class for all models in `Lightning`. `Lightning.LightningModule` is a subclass of `torch.nn.Module` and provides additional functionality for the training and testing of neural networks. The class `Lightning.LightningModule` is described in the [Lightning documentation](#).

- Here we simply add the NN Model to the `fun_control` dictionary by calling the function `add_core_model_to_fun_control`:

```
from spotPython.light.netlightbase import NetLightBase
from spotPython.data.light_hyper_dict import LightHyperDict
from spotPython.hyperparameters.values import add_core_model_to_fun_control
add_core_model_to_fun_control(core_model=NetLightBase,
                             fun_control=fun_control,
                             hyper_dict= LightHyperDict)
```

The `NetLightBase` is a configurable neural network. The hyperparameters of the model are specified in the `core_model_hyper_dict` dictionary [\[SOURCE\]](#).

17.6 Step 6: Modify hyper_dict Hyperparameters for the Selected Algorithm aka core_model

spotPython provides functions for modifying the hyperparameters, their bounds and factors as well as for activating and de-activating hyperparameters without re-compilation of the Python source code. These functions were described in Section 12.6.

 Caution: Small number of epochs for demonstration purposes

- `epochs` and `patience` are set to small values for demonstration purposes. These values are too small for a real application.
- More resonable values are, e.g.:
 - `modify_hyper_parameter_bounds(fun_control, "epochs", bounds=[7, 9])` and
 - `modify_hyper_parameter_bounds(fun_control, "patience", bounds=[2, 7])`

```
from spotPython.hyperparameters.values import modify_hyper_parameter_bounds
```

```
modify_hyper_parameter_bounds(fun_control, "l1", bounds=[5,8])
modify_hyper_parameter_bounds(fun_control, "epochs", bounds=[6,13])
modify_hyper_parameter_bounds(fun_control, "batch_size", bounds=[2, 8])
```

```
from spotPython.hyperparameters.values import modify_hyper_parameter_levels
modify_hyper_parameter_levels(fun_control, "optimizer",["Adam", "AdamW", "Adamax", "NAdam"]
# modify_hyper_parameter_levels(fun_control, "optimizer", ["Adam"])
```

Now, the dictionary `fun_control` contains all information needed for the hyperparameter tuning. Before the hyperparameter tuning is started, it is recommended to take a look at the experimental design. The method `gen_design_table` [\[SOURCE\]](#) generates a design table as follows:

```
from spotPython.utils.eda import gen_design_table
print(gen_design_table(fun_control))
```

name	type	default	lower	upper	transform
l1	int	3	5	8	transform_power_2_int
epochs	int	4	6	13	transform_power_2_int
batch_size	int	4	2	8	transform_power_2_int

act_fn	factor	ReLU		0		5		None	
optimizer	factor	SGD		0		3		None	
dropout_prob	float	0.01		0		0.25		None	
lr_mult	float	1.0		0.1		10		None	
patience	int	2		2		6		transform_power_2_int	
initialization	factor	Default		0		2		None	

This allows to check if all information is available and if the information is correct.

i Note: Hyperparameters of the Tuned Model and the `fun_control` Dictionary

The updated `fun_control` dictionary can be shown with the command `fun_control["core_model_hyper_dict"]`.

17.7 Step 7: Data Splitting, the Objective (Loss) Function and the Metric

17.7.1 Evaluation

The evaluation procedure requires the specification of two elements:

1. the way how the data is split into a train and a test set (see Section 12.7.1)
2. the loss function (and a metric).

 Caution: Data Splitting in Lightning

- The data splitting is handled by `Lightning`.

17.7.2 Loss Functions and Metrics

The loss function is specified in the configurable network class [\[SOURCE\]](#) We will use CrossEntropy loss for the multiclass-classification task.

17.7.3 Metric

- We will use the MAP@k metric [\[SOURCE\]](#) for the evaluation of the model.
- An example, how this metric works, is shown in the Appendix, see Section {Section 17.12.3}.

Similar to the loss function, the metric is specified in the configurable network class [\[SOURCE\]](#).

Caution: Loss Function and Metric in Lightning

- The loss function and the metric are not hyperparameters that can be tuned with `spotPython`.
- They are handled by `Lightning`.

17.8 Step 8: Calling the SPOT Function

17.8.1 Preparing the SPOT Call

The following code passes the information about the parameter ranges and bounds to `spot`. It extracts the variable types, names, and bounds

```
from spotPython.hyperparameters.values import (get_bound_values,
        get_var_name,
        get_var_type,)
var_type = get_var_type(fun_control)
var_name = get_var_name(fun_control)
lower = get_bound_values(fun_control, "lower")
upper = get_bound_values(fun_control, "upper")
```

17.8.2 The Objective Function fun

The objective function `fun` from the class `HyperLight` [\[SOURCE\]](#) is selected next. It implements an interface from PyTorch's training, validation, and testing methods to `spotPython`.

```
from spotPython.fun.hyperlight import HyperLight
fun = HyperLight().fun
```

17.8.3 Starting the Hyperparameter Tuning

The `spotPython` hyperparameter tuning is started by calling the `Spot` function [\[SOURCE\]](#) as described in Section [12.8.4](#).

```

import numpy as np
from spotPython.spot import spot
from math import inf
spot_tuner = spot.Spot(fun=fun,
                        lower = lower,
                        upper = upper,
                        fun_evals = inf,
                        max_time = MAX_TIME,
                        tolerance_x = np.sqrt(np.spacing(1)),
                        var_type = var_type,
                        var_name = var_name,
                        show_progress= True,
                        fun_control = fun_control,
                        design_control={"init_size": INIT_SIZE},
                        surrogate_control={"noise": True,
                                         "min_theta": -4,
                                         "max_theta": 3,
                                         "n_theta": len(var_name),
                                         "model_fun_evals": 10_000,
                                         })

spot_tuner.run()

```

config: {'l1': 256, 'epochs': 4096, 'batch_size': 32, 'act_fn': ReLU(), 'optimizer': 'AdamW'

Validate metric	DataLoader 0
hp_metric	2.277459144592285
val_acc	0.2614840865135193
val_loss	2.277459144592285
valid_mapk	0.3560313582420349

config: {'l1': 32, 'epochs': 128, 'batch_size': 256, 'act_fn': LeakyReLU(), 'optimizer': 'Ad

Validate metric	DataLoader 0
hp_metric	2.3159217834472656

val_acc	0.19434629380702972
val_loss	2.3159217834472656
valid_mapk	0.3128134608268738

config: {'l1': 128, 'epochs': 256, 'batch_size': 8, 'act_fn': Swish(), 'optimizer': 'NAdam',

Validate metric	DataLoader 0
hp_metric	2.4582345485687256
val_acc	0.08480565249919891
val_loss	2.4582345485687256
valid_mapk	0.16473765671253204

config: {'l1': 64, 'epochs': 512, 'batch_size': 16, 'act_fn': Sigmoid(), 'optimizer': 'Adam',

Validate metric	DataLoader 0
hp_metric	2.36840558052063
val_acc	0.16961130499839783
val_loss	2.36840558052063
valid_mapk	0.2375841736793518

config: {'l1': 64, 'epochs': 4096, 'batch_size': 64, 'act_fn': ReLU(), 'optimizer': 'Adamax',

Validate metric	DataLoader 0
hp_metric	2.2885937690734863
val_acc	0.24028268456459045
val_loss	2.2885937690734863
valid_mapk	0.35175541043281555

config: {'l1': 128, 'epochs': 4096, 'batch_size': 4, 'act_fn': ReLU(), 'optimizer': 'AdamW',

Validate metric	DataLoader 0
hp_metric	2.2994933128356934
val_acc	0.22614841163158417
val_loss	2.2994933128356934
valid_mapk	0.31924888491630554

spotPython tuning: 2.277459144592285 [#####---] 67.63%

config: {'l1': 64, 'epochs': 4096, 'batch_size': 8, 'act_fn': ReLU(), 'optimizer': 'AdamW',

Validate metric	DataLoader 0
hp_metric	2.243631362915039
val_acc	0.30035334825515747
val_loss	2.243631362915039
valid_mapk	0.3738425672054291

spotPython tuning: 2.243631362915039 [#####--] 81.53%

config: {'l1': 64, 'epochs': 2048, 'batch_size': 128, 'act_fn': ReLU(), 'optimizer': 'AdamW',

Validate metric	DataLoader 0
hp_metric	2.2953238487243652
val_acc	0.23674911260604858
val_loss	2.2953238487243652
valid_mapk	0.35479357838630676


```
spotPython tuning: 2.243631362915039 [#####-] 85.60%
```

```
config: {'l1': 64, 'epochs': 8192, 'batch_size': 4, 'act_fn': ReLU(), 'optimizer': 'Adamax',
```

Validate metric	DataLoader 0
hp_metric	2.314422845840454
val_acc	0.19434629380702972
val_loss	2.314422845840454
valid_mapk	0.3075117766857147

```
spotPython tuning: 2.243631362915039 [#####] 100.00% Done...
```

```
<spotPython.spot.spot.Spot at 0x105722140>
```

17.9 Step 9: Tensorboard

The textual output shown in the console (or code cell) can be visualized with Tensorboard.

```
tensorboard --logdir="runs/"
```

Further information can be found in the [PyTorch Lightning documentation](#) for Tensorboard.

17.10 Step 10: Results

After the hyperparameter tuning run is finished, the results can be analyzed as described in Section [12.10](#).

```
spot_tuner.plot_progress(log_y=False,  
    filename="./figures/" + experiment_name+"_progress.png")
```

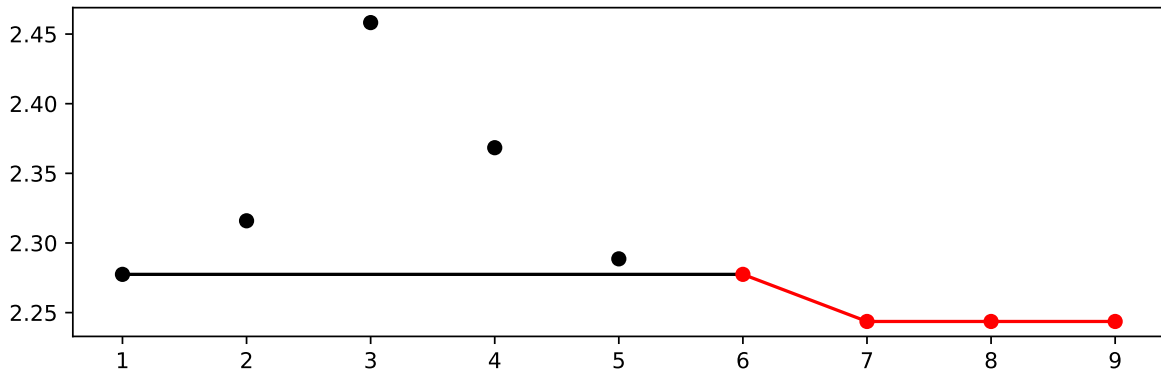


Figure 17.1: Progress plot. *Black* dots denote results from the initial design. *Red* dots illustrate the improvement found by the surrogate model based optimization.

```
from spotPython.utils.eda import gen_design_table
print(gen_design_table(fun_control=fun_control, spot=spot_tuner))
```

name	type	default	lower	upper	tuned	transform
l1	int	3	5.0	8.0	6.0	transform_po
epochs	int	4	6.0	13.0	12.0	transform_po
batch_size	int	4	2.0	8.0	3.0	transform_po
act_fn	factor	ReLU	0.0	5.0	2.0	None
optimizer	factor	SGD	0.0	3.0	1.0	None
dropout_prob	float	0.01	0.0	0.25	0.0	None
lr_mult	float	1.0	0.1	10.0	8.678730185374194	None
patience	int	2	2.0	6.0	2.0	transform_po
initialization	factor	Default	0.0	2.0	0.0	None

```
spot_tuner.plot_importance(threshold=0.025,
                           filename="./figures/" + experiment_name+"_importance.png")
```

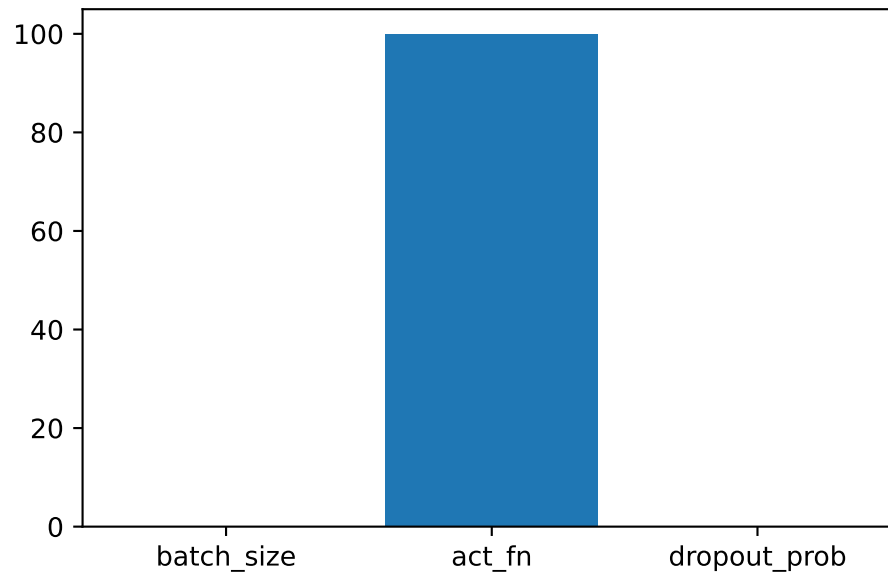


Figure 17.2: Variable importance plot, threshold 0.025.

17.10.1 Get the Tuned Architecture

```
from spotPython.light.utils import get_tuned_architecture
config = get_tuned_architecture(spot_tuner, fun_control)
```

- Test on the full data set

```
from spotPython.light.traintest import test_model
test_model(config, fun_control)
```

Test metric	DataLoader 0
hp_metric	2.2711098194122314
test_mapk_epoch	0.3448033630847931
val_acc	0.24328146874904633
val_loss	2.2711098194122314

(2.2711098194122314, 0.24328146874904633)

```
from spotPython.light.traintest import load_light_from_checkpoint

model_loaded = load_light_from_checkpoint(config, fun_control)
```

Loading model from runs/lightning_logs/64_4096_8_ReLU()_AdamW_0.0_8.678730185374194_4_Default

17.10.2 Cross Validation With Lightning

- The KFold class from `sklearn.model_selection` is used to generate the folds for cross-validation.
- These mechanism is used to generate the folds for the final evaluation of the model.
- The `CrossValidationDataModule` class [\[SOURCE\]](#) is used to generate the folds for the hyperparameter tuning process.
- It is called from the `cv_model` function [\[SOURCE\]](#).

```
from spotPython.light.traintest import cv_model
# set the number of folds to 10
fun_control["k_folds"] = 10
cv_model(config, fun_control)
```

```
k: 0
Train Dataset Size: 636
Val Dataset Size: 71
```

Validate metric	DataLoader 0
hp_metric	2.2043471336364746
val_acc	0.3239436745643616
val_loss	2.2043471336364746
valid_mapk	0.4107142686843872

```
train_model result: {'valid_mapk': 0.4107142686843872, 'val_loss': 2.2043471336364746, 'val_
k: 1
Train Dataset Size: 636
Val Dataset Size: 71
```

Validate metric	DataLoader 0
hp_metric	2.26342511177063
val_acc	0.28169015049934387
val_loss	2.26342511177063
valid_mapk	0.36177247762680054

train_model result: {'valid_mapk': 0.36177247762680054, 'val_loss': 2.26342511177063, 'val_acc': 0.28169015049934387, 'val_mapk': 0.36177247762680054}

k: 2

Train Dataset Size: 636

Val Dataset Size: 71

Validate metric	DataLoader 0
hp_metric	2.331244468688965
val_acc	0.1690140813589096
val_loss	2.331244468688965
valid_mapk	0.2172619104385376

train_model result: {'valid_mapk': 0.2172619104385376, 'val_loss': 2.331244468688965, 'val_acc': 0.1690140813589096, 'val_mapk': 0.2172619104385376}

k: 3

Train Dataset Size: 636

Val Dataset Size: 71

Validate metric	DataLoader 0
hp_metric	2.285844564437866
val_acc	0.22535210847854614
val_loss	2.285844564437866
valid_mapk	0.3379629850387573

train_model result: {'valid_mapk': 0.3379629850387573, 'val_loss': 2.285844564437866, 'val_acc': 0.22535210847854614, 'val_mapk': 0.3379629850387573}

k: 4

Train Dataset Size: 636

Val Dataset Size: 71

Validate metric	DataLoader 0
hp_metric	2.348761796951294
val_acc	0.18309858441352844
val_loss	2.348761796951294
valid_mapk	0.25264549255371094

train_model result: {'valid_mapk': 0.25264549255371094, 'val_loss': 2.348761796951294, 'val_acc': 0.18309858441352844, 'val_mapk': 0.25264549255371094, 'k': 5}

Train Dataset Size: 636

Val Dataset Size: 71

Validate metric	DataLoader 0
hp_metric	2.3252155780792236
val_acc	0.2112676054239273
val_loss	2.3252155780792236
valid_mapk	0.3343254327774048

train_model result: {'valid_mapk': 0.3343254327774048, 'val_loss': 2.3252155780792236, 'val_acc': 0.2112676054239273, 'val_mapk': 0.3343254327774048, 'k': 6}

Train Dataset Size: 636

Val Dataset Size: 71

Validate metric	DataLoader 0
hp_metric	2.289710521697998
val_acc	0.23943662643432617
val_loss	2.289710521697998
valid_mapk	0.33564817905426025

train_model result: {'valid_mapk': 0.33564817905426025, 'val_loss': 2.289710521697998, 'val_acc': 0.23943662643432617, 'val_mapk': 0.33564817905426025, 'k': 7}

Train Dataset Size: 637

Val Dataset Size: 70

Validate metric	DataLoader 0
hp_metric	2.3087875843048096
val_acc	0.2142857164144516
val_loss	2.3087875843048096
valid_mapk	0.29629626870155334

train_model result: {'valid_mapk': 0.29629626870155334, 'val_loss': 2.3087875843048096, 'val.
k: 8
Train Dataset Size: 637
Val Dataset Size: 70

Validate metric	DataLoader 0
hp_metric	2.3037796020507812
val_acc	0.2142857164144516
val_loss	2.3037796020507812
valid_mapk	0.34876543283462524

train_model result: {'valid_mapk': 0.34876543283462524, 'val_loss': 2.3037796020507812, 'val.
k: 9
Train Dataset Size: 637
Val Dataset Size: 70

Validate metric	DataLoader 0
hp_metric	2.3446907997131348
val_acc	0.18571428954601288
val_loss	2.3446907997131348
valid_mapk	0.29783952236175537

train_model result: {'valid_mapk': 0.29783952236175537, 'val_loss': 2.3446907997131348, 'val.
0.31932319700717926

i Note: Evaluation for the Final Comparison

- This is the evaluation that will be used in the comparison.

17.10.3 Detailed Hyperparameter Plots

```
filename = "./figures/" + experiment_name
spot_tuner.plot_important_hyperparameter_contour(filename=filename)
```

batch_size: 0.13297357834444154
act_fn: 100.0
dropout_prob: 0.12166398545327557

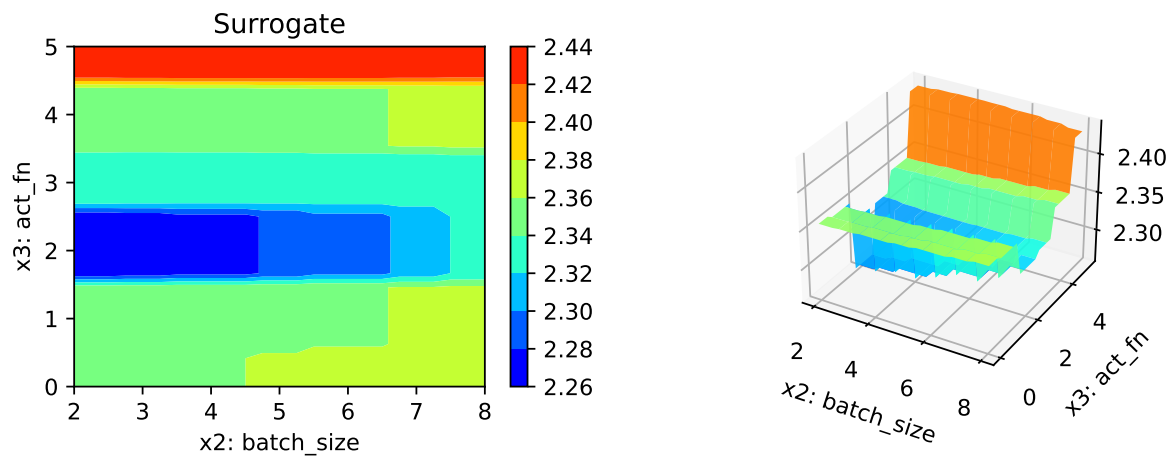
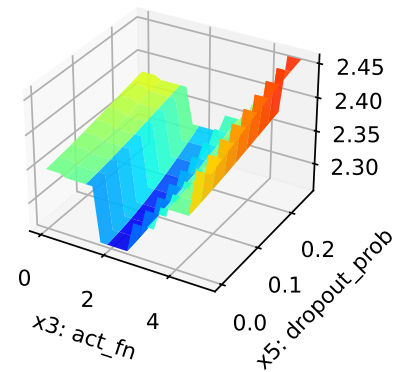
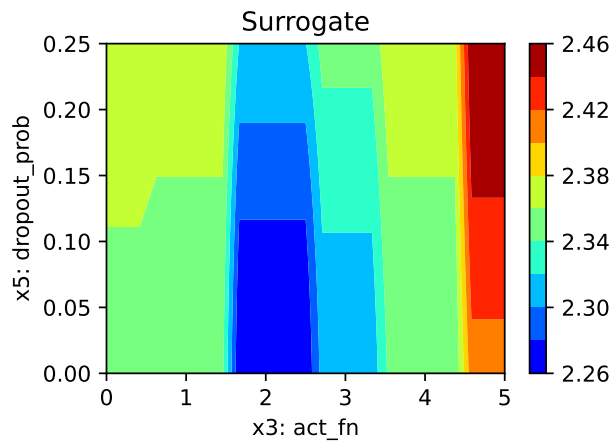
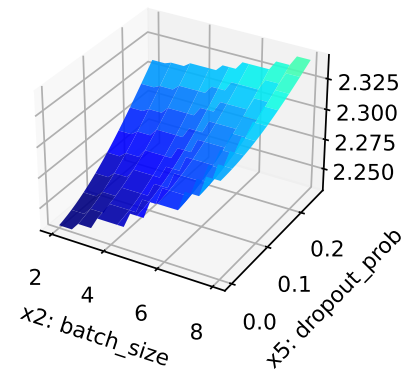
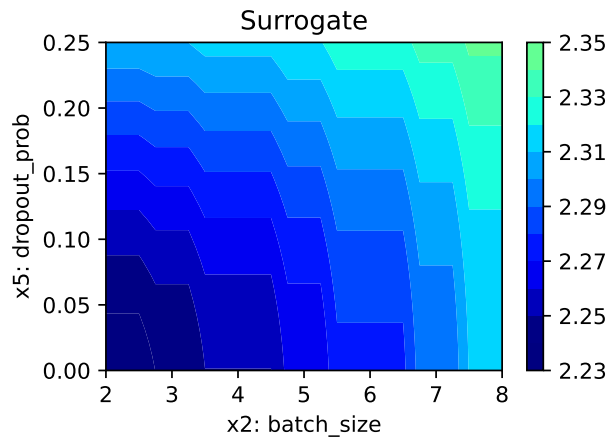


Figure 17.3: Contour plots.



17.10.4 Parallel Coordinates Plot

```
spot_tuner.parallel_plot()
```

Unable to display output for mime type(s): text/html

Parallel coordinates plots

Unable to display output for mime type(s): text/html

17.10.5 Plot all Combinations of Hyperparameters

- Warning: this may take a while.

```
PLOT_ALL = False
if PLOT_ALL:
    n = spot_tuner.k
    for i in range(n-1):
        for j in range(i+1, n):
            spot_tuner.plot_contour(i=i, j=j, min_z=min_z, max_z = max_z)
```

17.10.6 Visualizing the Activation Distribution

i Reference:

- The following code is based on [\[PyTorch Lightning TUTORIAL 2: ACTIVATION FUNCTIONS\]](#), Author: Phillip Lippe, License: [\[CC BY-SA\]](#), Generated: 2023-03-15T09:52:39.179933.

After we have trained the models, we can look at the actual activation values that find inside the model. For instance, how many neurons are set to zero in ReLU? Where do we find most values in Tanh? To answer these questions, we can write a simple function which takes a trained model, applies it to a batch of images, and plots the histogram of the activations inside the network:

```
from spotPython.torch.activation import Sigmoid, Tanh, ReLU, LeakyReLU, ELU, Swish
act_fn_by_name = {"sigmoid": Sigmoid, "tanh": Tanh, "relu": ReLU, "leakyrelu": LeakyReLU,
```

```
from spotPython.hyperparameters.values import get_one_config_from_X
X = spot_tuner.to_all_dim(spot_tuner.min_X.reshape(1,-1))
config = get_one_config_from_X(X, fun_control)
model = fun_control["core_model"](**config, _L_in=64, _L_out=11)
model
```

```
NetLightBase(
  (train_mapk): MAPK()
  (valid_mapk): MAPK()
  (test_mapk): MAPK()
  (layers): Sequential(
    (0): Linear(in_features=64, out_features=64, bias=True)
```

```

(1): ReLU()
(2): Dropout(p=0.0, inplace=False)
(3): Linear(in_features=64, out_features=32, bias=True)
(4): ReLU()
(5): Dropout(p=0.0, inplace=False)
(6): Linear(in_features=32, out_features=32, bias=True)
(7): ReLU()
(8): Dropout(p=0.0, inplace=False)
(9): Linear(in_features=32, out_features=16, bias=True)
(10): ReLU()
(11): Dropout(p=0.0, inplace=False)
(12): Linear(in_features=16, out_features=11, bias=True)
)
)

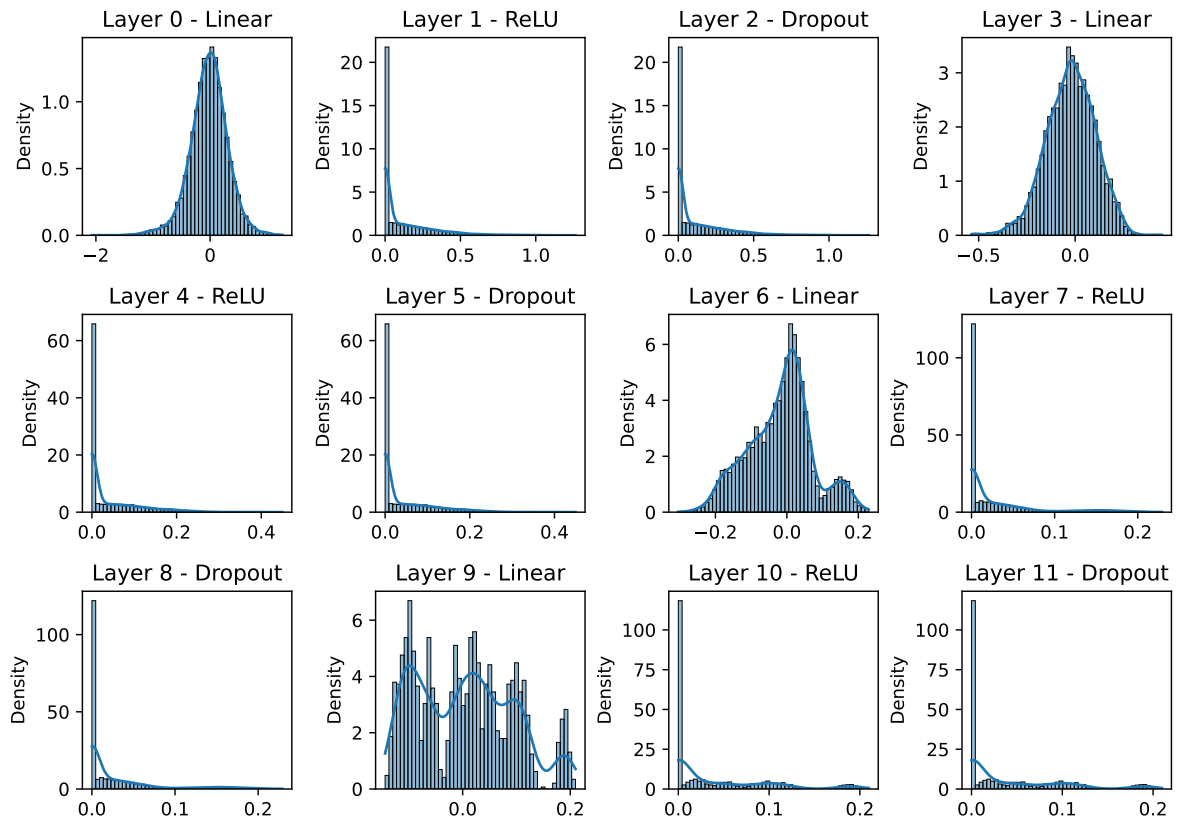
```

```

from spotPython.utils.eda import visualize_activations
visualize_activations(model, color=f"C{0}")

```

Activation distribution for activation function ReLU()



17.11 Submission

```
import numpy as np
import pandas as pd
from sklearn.preprocessing import OrdinalEncoder

import pandas as pd
from sklearn.preprocessing import OrdinalEncoder
train_df = pd.read_csv('./data/VBDP/train.csv', index_col=0)
# remove the id column
# train_df = train_df.drop(columns=['id'])
n_samples = train_df.shape[0]
n_features = train_df.shape[1] - 1
```

```
target_column = "prognosis"
# Encode our prognosis labels as integers for easier decoding later
enc = OrdinalEncoder()
y = enc.fit_transform(train_df[[target_column]])
test_df = pd.read_csv('./data/VBDP/test.csv', index_col=0)
test_df
```

id	sudden_fever	headache	mouth_bleed	nose_bleed	muscle_pain	joint_pain	vomiting	rash
707	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
708	1.0	1.0	0.0	1.0	0.0	1.0	1.0	1.0
709	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0
710	0.0	1.0	0.0	0.0	0.0	1.0	1.0	1.0
711	0.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0
712	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0
713	1.0	0.0	1.0	0.0	1.0	1.0	1.0	1.0
714	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0
715	1.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0
716	0.0	1.0	0.0	0.0	0.0	1.0	1.0	0.0
717	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0
718	1.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0
719	1.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0
720	1.0	0.0	0.0	1.0	0.0	1.0	1.0	1.0
721	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0
722	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
723	0.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0
724	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
725	1.0	0.0	1.0	1.0	1.0	1.0	0.0	1.0
726	1.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0
727	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0
728	1.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0
729	1.0	1.0	0.0	0.0	1.0	1.0	1.0	1.0
730	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
731	1.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0
732	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
733	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0
734	0.0	1.0	0.0	1.0	0.0	0.0	1.0	1.0
735	1.0	1.0	0.0	1.0	1.0	0.0	0.0	1.0
736	1.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0
737	1.0	0.0	0.0	0.0	1.0	1.0	0.0	1.0
738	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
739	1.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0
740	0.0	1.0	1.0	1.0	0.0	1.0	0.0	0.0
741	0.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0
742	1.0	1.0	0.0	1.0	1.0	0.0	0.0	0.0
743	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
744	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0
745	1.0	1.0	1.0	0.0	1.0	0.0	0.0	1.0
746	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0
747	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0
748	0.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0
749	0.0	1.0	0.0	1.0	0.0	1.0	1.0	0.0
750	0.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0
751	0.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0
752	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0
753	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0
754	1.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0
755	0.0	1.0	0.0	0.0	0.0	1.0	1.0	0.0
756	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
757	1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0

```
import torch
X_tensor = torch.Tensor(test_df.values)
X_tensor = X_tensor.to(fun_control["device"])
```

```
y = model_loaded(X_tensor)
y.shape
```

```
torch.Size([303, 11])
```

```
# convert the predictions to a numpy array
y = y.cpu().detach().numpy()
y
```

```
array([[4.9513872e-03, 1.3773427e-02, 3.5640836e-01, ..., 5.5254422e-02,
        5.4633325e-01, 2.1851044e-02],
       [9.4269350e-02, 1.1495395e-01, 1.5774296e-01, ..., 1.5673271e-01,
        1.8804695e-01, 8.8696286e-02],
       [3.4896255e-04, 3.5895796e-03, 5.3935391e-01, ..., 2.1820965e-01,
        1.9579418e-01, 3.9765742e-02],
       ...,
       [4.9555425e-14, 4.6767377e-06, 2.6950960e-05, ..., 7.5526498e-02,
        3.0034728e-09, 4.0841637e-06],
       [1.3232861e-07, 1.4623423e-03, 6.4026024e-03, ..., 3.5403693e-01,
        5.8086549e-05, 2.6099070e-03],
       [2.4606707e-04, 2.5668205e-03, 5.6955063e-01, ..., 1.3092868e-01,
        2.7033332e-01, 2.5506845e-02]], dtype=float32)
```

```
test_sorted_prediction_ids = np.argsort(-y, axis=1)
test_top_3_prediction_ids = test_sorted_prediction_ids[:, :3]
original_shape = test_top_3_prediction_ids.shape
test_top_3_prediction = enc.inverse_transform(test_top_3_prediction_ids.reshape(-1, 1))
test_top_3_prediction = test_top_3_prediction.reshape(original_shape)
test_df['prognosis'] = np.apply_along_axis(lambda x: np.array(' '.join(x), dtype="object"),
test_df['prognosis'].reset_index().to_csv('./data/VBDP/submission.csv', index=False)
```

17.12 Appendix

17.12.1 Differences to the spotPython Approaches for torch, sklearn and river

Caution: Data Loading in Lightning

- Data loading is handled independently from the `fun_control` dictionary by Lightning and PyTorch.
- In contrast to spotPython with torch, river and sklearn, the data sets are not added to the `fun_control` dictionary.

17.12.1.1 Specification of the Preprocessing Model

The `fun_control` dictionary, the torch, sklearn and river versions of spotPython allow the specification of a data preprocessing pipeline, e.g., for the scaling of the data or for the one-hot encoding of categorical variables, see Section 12.4. This feature is not used in the Lightning version.

Caution: Data preprocessing in Lightning

Lightning allows the data preprocessing to be specified in the `LightningDataModule` class. It is not considered here, because it should be computed at one location only.

17.12.2 Taking a Look at the Data

```
import torch
from spotPython.light.csvdataset import CSVDataset
from torch.utils.data import DataLoader
from torchvision.transforms import ToTensor

# Create an instance of CSVDataset
dataset = CSVDataset(csv_file="./data/VBDP/train.csv", train=True)
# show the dimensions of the input data
print(dataset[0][0].shape)
# show the first element of the input data
print(dataset[0][0])
# show the size of the dataset
print(f"Dataset Size: {len(dataset)}")
```



```
torch.Size([64])
tensor([[1., 1., 0., 1., 1., 1., 1., 0., 1., 1., 1., 1., 0., 0., 1., 1., 0., 0.,
        1., 0., 1., 0., 1., 1., 1., 1., 1., 1., 1., 0., 0., 1., 0., 0., 0., 0.,
        1., 0., 0., 0., 0., 0., 1., 0., 1., 0., 1., 0., 0., 0., 0., 1., 0., 1.,
        0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.]])
Dataset Size: 707
```

```
# Set batch size for DataLoader
batch_size = 3
# Create DataLoader
dataloader = DataLoader(dataset, batch_size=batch_size, shuffle=True)

# Iterate over the data in the DataLoader
for batch in dataloader:
    inputs, targets = batch
    print(f"Batch Size: {inputs.size(0)}")
    print("-----")
    print(f"Inputs: {inputs}")
    print(f"Targets: {targets}")
    break
```

Batch Size: 3

```
-----
Inputs: tensor([[0., 0., 1., 1., 1., 1., 0., 1., 1., 1., 0., 0., 1., 1., 0., 1., 1., 0.,
        1., 1., 1., 0., 1., 1., 1., 1., 0., 1., 0., 0., 1., 1., 1., 0., 0., 0.,
        1., 1., 0., 0., 1., 1., 1., 0., 1., 0., 1., 1., 1., 1., 1., 1., 1., 1.,
        1., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
        [0., 0., 0., 0., 0., 1., 0., 0., 0., 0., 0., 0., 0., 0., 1., 0., 1., 1., 0.,
        1., 1., 1., 1., 1., 1., 0., 1., 1., 1., 0., 0., 1., 0., 0., 0., 1.,
        1., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
        0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
        [0., 0., 0., 0., 0., 0., 0., 0., 1., 0., 0., 0., 1., 0., 0., 0., 0., 0., 0.,
        0., 0., 0., 0., 0., 0., 1., 0., 0., 0., 1., 0., 0., 1., 0., 0., 0.,
        0., 0., 0., 0., 0., 0., 1., 0., 0., 0., 0., 1., 1., 0., 0., 0., 0., 0.,
        1., 0., 0., 0., 0., 1., 1., 1., 0., 0.]])
Targets: tensor([ 5, 10,  1])
```

17.12.3 The MAPK Metric

Here is an example how the MAPK metric is calculated.

```

from spotPython.torch.mapk import MAPK
import torch
mapk = MAPK(k=2)
target = torch.tensor([0, 1, 2, 2])
preds = torch.tensor(
    [
        [0.5, 0.2, 0.2], # 0 is in top 2
        [0.3, 0.4, 0.2], # 1 is in top 2
        [0.2, 0.4, 0.3], # 2 is in top 2
        [0.7, 0.2, 0.1], # 2 isn't in top 2
    ]
)
mapk.update(preds, target)
print(mapk.compute()) # tensor(0.6250)

```

tensor(0.6250)

18 Documentation of the Sequential Parameter Optimization

This document describes the Spot features.

18.1 Example: spot

```
import numpy as np
from math import inf
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
from scipy.optimize import shgo
from scipy.optimize import direct
from scipy.optimize import differential_evolution
import matplotlib.pyplot as plt
```

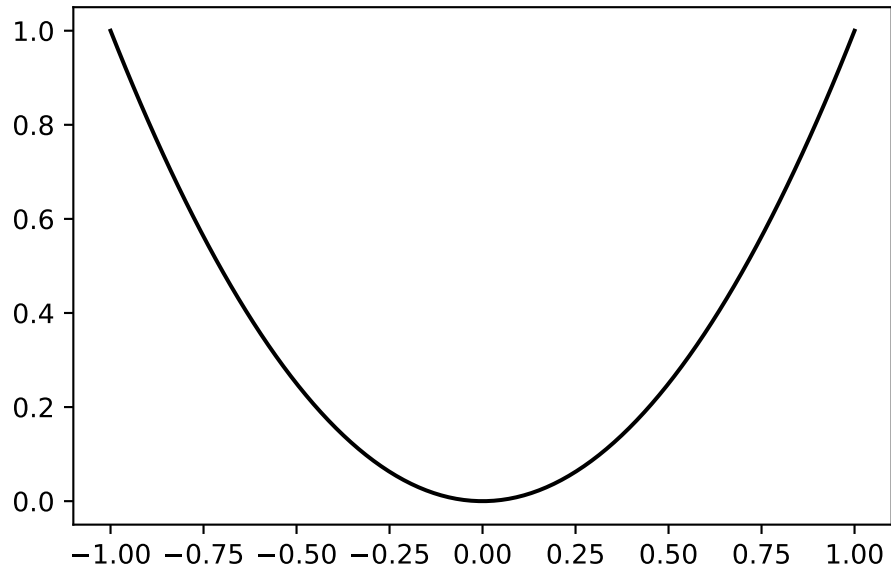
18.1.1 The Objective Function

The spotPython package provides several classes of objective functions. We will use an analytical objective function, i.e., a function that can be described by a (closed) formula:

$$f(x) = x^2$$

```
fun = analytical().fun_sphere

x = np.linspace(-1,1,100).reshape(-1,1)
y = fun(x)
plt.figure()
plt.plot(x,y, "k")
plt.show()
```



```
spot_1 = spot.Spot(fun=fun,
                    lower = np.array([-10]),
                    upper = np.array([100]),
                    fun_evals = 7,
                    fun_repeats = 1,
                    max_time = inf,
                    noise = False,
                    tolerance_x = np.sqrt(np.spacing(1)),
                    var_type=["num"],
                    infill_criterion = "y",
                    n_points = 1,
                    seed=123,
                    log_level = 50,
                    show_models=True,
                    fun_control = {},
                    design_control={"init_size": 5,
                                   "repeats": 1},
                    surrogate_control={"noise": False,
                                       "cod_type": "norm",
                                       "min_theta": -4,
                                       "max_theta": 3,
                                       "n_theta": 1,
                                       "model_optimizer": differential_evolution,
                                       "model_fun_evals": 1000,
```

})

`spot`'s `__init__` method sets the control parameters. There are two parameter groups:

1. external parameters can be specified by the user
2. internal parameters, which are handled by `spot`.

18.1.2 External Parameters

external parameter	type	description	default	mandatory
<code>fun</code>	object	objective function		yes
<code>lower</code>	array	lower bound		yes
<code>upper</code>	array	upper bound		yes
<code>fun_evals</code>	int	number of function evaluations	15	no
<code>fun_evals</code>	int	number of function evaluations	15	no
<code>fun_control</code>	dict	noise etc.	{}	n
<code>max_time</code>	int	max run time budget	<code>inf</code>	no
<code>noise</code>	bool	if repeated evaluations of <code>fun</code> results in different values, then <code>noise</code> should be set to <code>True</code> .	<code>False</code>	no

external parameter	type	description	default	mandatory
<code>tolerance_x</code>	float	tolerance for new x solutions. Minimum distance of new solutions, generated by <code>suggest_new_X</code> , to already existing solutions. If zero (which is the default), every new solution is accepted.	0	no
<code>var_type</code>	list	list of type information, can be either "num" or "factor"	["num"]	no
<code>infill_criterion</code>	string	Can be "y", "s", "ei" (negative expected improvement), or "all"	"y"	no
<code>n_points</code>	int	number of infill points	1	no
<code>seed</code>	int	initial seed. If <code>Spot.run()</code> is called twice, different results will be generated. To reproduce results, the <code>seed</code> can be used.	123	no

external parameter	type	description	default	mandatory
log_level	int	log level with the following settings: NOTSET (0), DEBUG (10: Detailed information, typically of interest only when diagnosing problems.), INFO (20: Confirmation that things are working as expected.), WARNING (30: An indication that something unexpected happened, or indicative of some problem in the near future (e.g. 'disk space low'). The software is still working as expected.), ERROR (40: Due to a more serious problem, the software has not been able to perform some function.), and CRITICAL (50: A serious error, indicating that the program itself may be unable to continue running.)	50	no

external parameter	type	description	default	mandatory
<code>show_models</code>	bool	Plot model. Currently only 1-dim functions are supported	False	no
<code>design</code>	object	experimental design	None	no
<code>design_control</code>	dict	control parameters	see below	no
<code>surrogate</code>		surrogate model	kriging	no
<code>surrogate_control</code>	dict	control parameters	see below	no
<code>optimizer</code>	object	optimizer	see below	no
<code>optimizer_control</code>	dict	control parameters	see below	no

- Besides these single parameters, the following parameter dictionaries can be specified by the user:

- `fun_control`
- `design_control`
- `surrogate_control`
- `optimizer_control`

18.2 The `fun_control` Dictionary

external parameter	type	description	default	mandatory
<code>sigma</code>	float	noise: standard deviation	0	yes
<code>seed</code>	int	seed for rng	124	yes

18.3 The `design_control` Dictionary

external parameter	type	description	default	mandatory
<code>init_size</code>	int	initial sample size	10	yes

external parameter	type	description	default	mandatory
repeats	int	number of repeats of the initial sammples	1	yes

18.4 The surrogate_control Dictionary

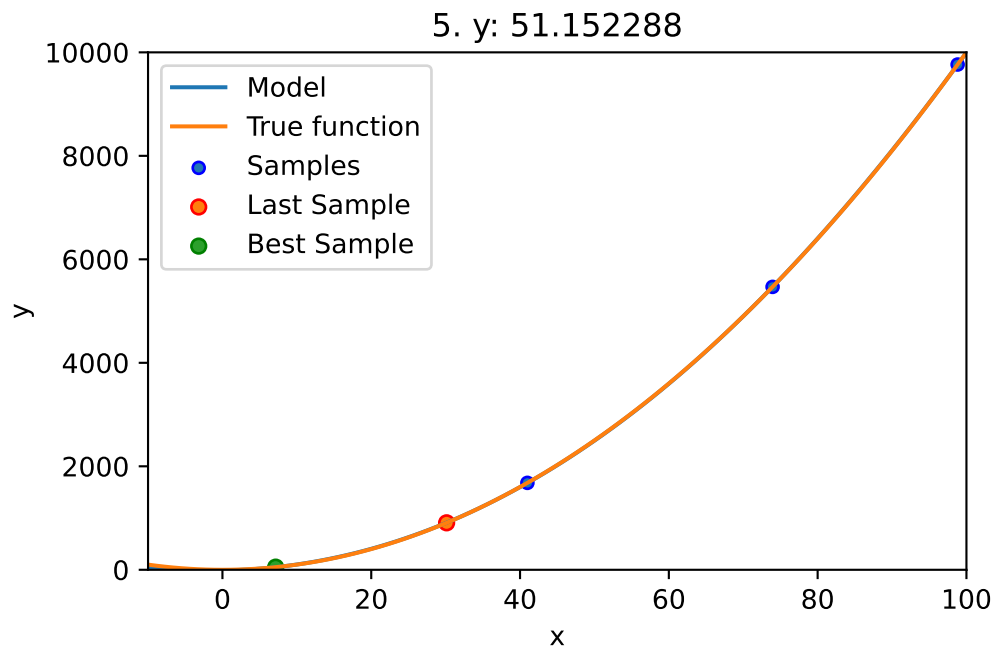
external parameter	type	description	default	mandatory
noise				
model_optimizer	object	optimizer	differential_evolution	
model_fun_evals				
min_theta			-3.	
max_theta			3.	
n_theta			1	
n_p			1	
optim_p			False	
cod_type			"norm"	
var_type				
use_cod_y	bool		False	

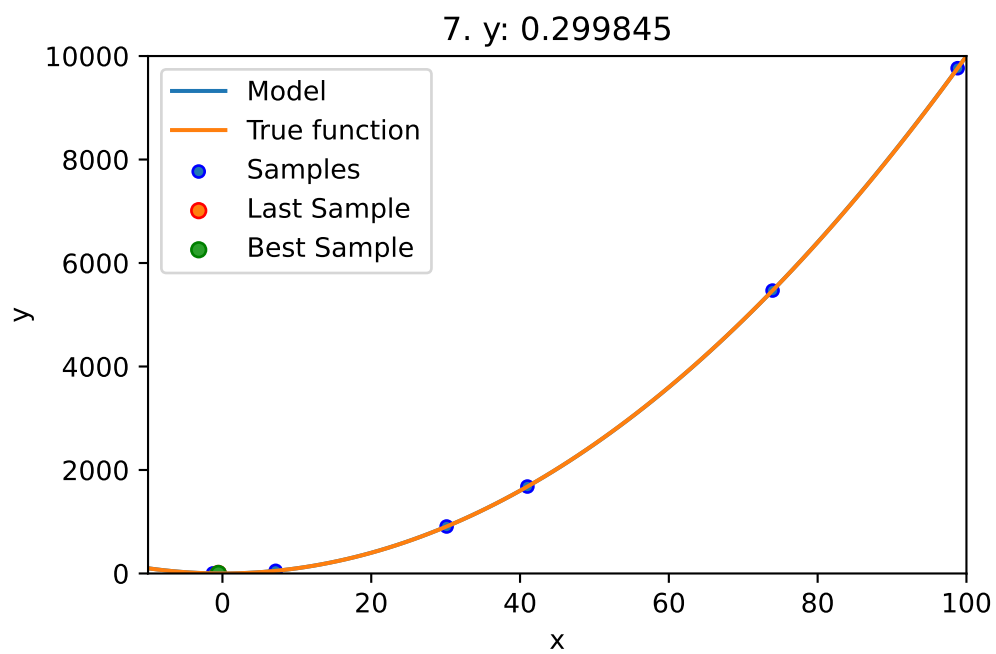
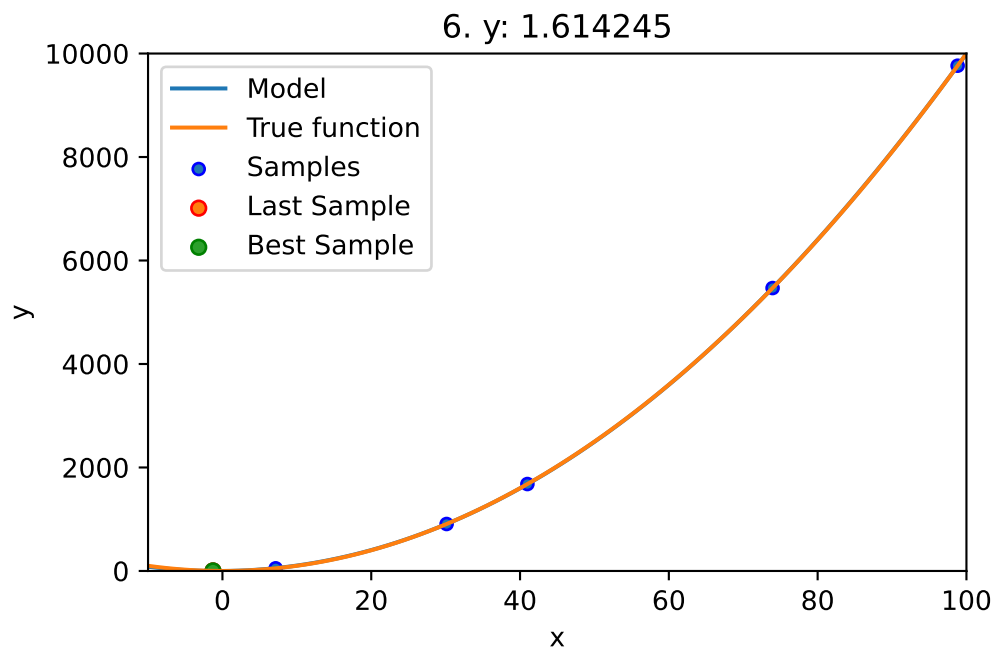
18.5 The optimizer_control Dictionary

external parameter	type	description	default	mandatory
max_iter	int	max number of iterations. Note: these are the cheap evaluations on the surrogate.	1000	no

18.6 Run

```
spot_1.run()
```





<spotPython.spot.spot.Spot at 0x14ce9ed10>

18.7 Print the Results

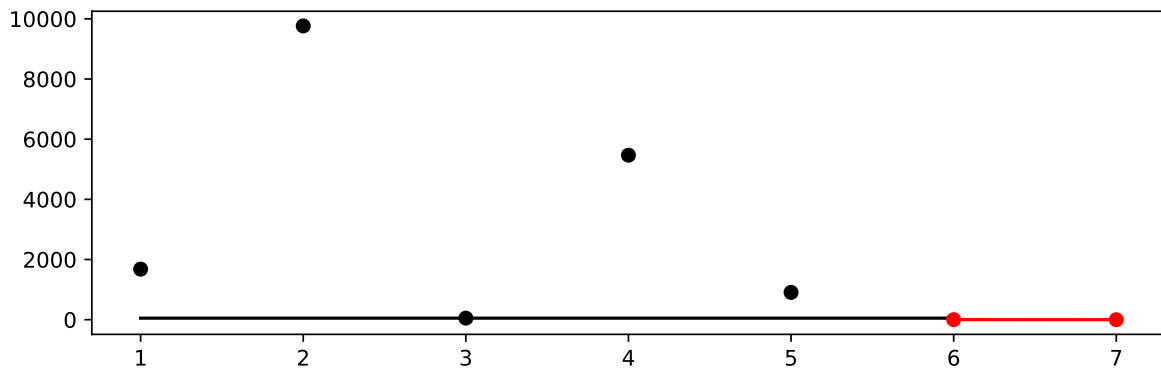
```
spot_1.print_results()
```

```
min y: 0.29984480579304645  
x0: -0.5475808668982568
```

```
[['x0', -0.5475808668982568]]
```

18.8 Show the Progress

```
spot_1.plot_progress()
```

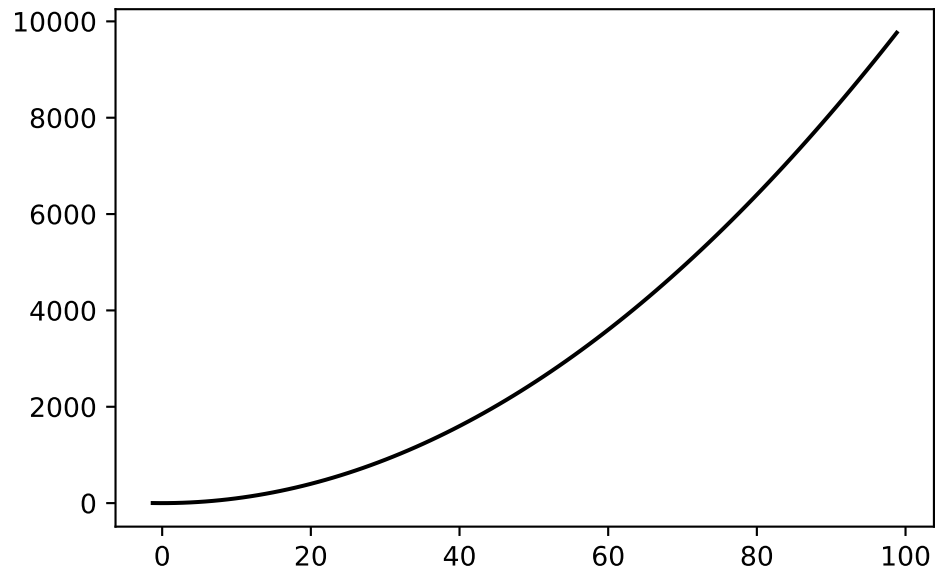


18.9 Visualize the Surrogate

- The plot method of the **kriging** surrogate is used.
- Note: the plot uses the interval defined by the ranges of the natural variables.

```
spot_1.surrogate.plot()
```

<Figure size 2700x1800 with 0 Axes>



18.10 Init: Build Initial Design

```
from spotPython.design.spacefilling import spacefilling
from spotPython.build.kriging import Kriging
from spotPython.fun.objectivefunctions import analytical
gen = spacefilling(2)
rng = np.random.RandomState(1)
lower = np.array([-5,-0])
upper = np.array([10,15])
fun = analytical().fun_branin
fun_control = {"sigma": 0,
               "seed": 123}

X = gen.scipy_lhd(10, lower=lower, upper = upper)
print(X)
y = fun(X, fun_control=fun_control)
print(y)
```

```
[[ 8.97647221 13.41926847]
 [ 0.66946019  1.22344228]
 [ 5.23614115 13.78185824]
 [ 5.6149825  11.5851384 ]
```

```

[-1.72963184  1.66516096]
[-4.26945568  7.1325531 ]
[ 1.26363761 10.17935555]
[ 2.88779942  8.05508969]
[-3.39111089  4.15213772]
[ 7.30131231  5.22275244]]
[128.95676449  31.73474356 172.89678121 126.71295908  64.34349975
 70.16178611  48.71407916  31.77322887  76.91788181  30.69410529]

```

18.11 Replicability

Seed

```

gen = spacefilling(2, seed=123)
X0 = gen.scipy_lhd(3)
gen = spacefilling(2, seed=345)
X1 = gen.scipy_lhd(3)
X2 = gen.scipy_lhd(3)
gen = spacefilling(2, seed=123)
X3 = gen.scipy_lhd(3)
X0, X1, X2, X3

```

```

(array([[0.77254938, 0.31539299],
        [0.59321338, 0.93854273],
        [0.27469803, 0.3959685 ]]),
array([[0.78373509, 0.86811887],
        [0.06692621, 0.6058029 ],
        [0.41374778, 0.00525456]]),
array([[0.121357  , 0.69043832],
        [0.41906219, 0.32838498],
        [0.86742658, 0.52910374]]),
array([[0.77254938, 0.31539299],
        [0.59321338, 0.93854273],
        [0.27469803, 0.3959685 ]]))

```

18.12 Surrogates

18.12.1 A Simple Predictor

The code below shows how to use a simple model for prediction. Assume that only two (very costly) measurements are available:

1. $f(0) = 0.5$
2. $f(2) = 2.5$

We are interested in the value at $x_0 = 1$, i.e., $f(x_0 = 1)$, but cannot run an additional, third experiment.

```
from sklearn import linear_model
X = np.array([[0], [2]])
y = np.array([0.5, 2.5])
S_lm = linear_model.LinearRegression()
S_lm = S_lm.fit(X, y)
X0 = np.array([[1]])
y0 = S_lm.predict(X0)
print(y0)
```

[1.5]

Central Idea: Evaluation of the surrogate model S_{lm} is much cheaper (or / and much faster) than running the real-world experiment f .

18.13 Demo/Test: Objective Function Fails

SPOT expects `np.nan` values from failed objective function values. These are handled. Note: SPOT's counter considers only successful executions of the objective function.

```
import numpy as np
from spotPython.fun.objectivefunctions import analytical
from spotPython.spot import spot
import numpy as np
from math import inf
# number of initial points:
ni = 20
# number of points
n = 30
```

```

fun = analytical().fun_random_error
lower = np.array([-1])
upper = np.array([1])
design_control={"init_size": ni}

spot_1 = spot.Spot(fun=fun,
                    lower = lower,
                    upper= upper,
                    fun_evals = n,
                    show_progress=False,
                    design_control=design_control,)
spot_1.run()
# To check whether the run was successfully completed,
# we compare the number of evaluated points to the specified
# number of points.
assert spot_1.y.shape[0] == n

[      nan -0.9053821 -0.02203599 -0.21843718  0.78240941 -0.58120945
 -0.3923345  0.67234256          nan -0.68898927 -0.75129705  0.97550354
 0.41757584  0.0786237  0.82585329  0.23700598 -0.49274073 -0.82319082
      nan  0.1481835 ]
[-1.]

[-0.47259301]

[0.95541987]

[nan]
[0.17335968]

[nan]
[-0.58552368]
[-0.20126111]

[-0.60100809]
[-0.97897336]
[nan]

[-0.2748985]
[0.8359486]

```


[0.99035591]
[0.01641232]

[0.5629346]

18.14 PyTorch: Detailed Description of the Data Splitting

18.14.1 Description of the "train_hold_out" Setting

The "train_hold_out" setting is used by default. It uses the loss function specified in `fun_control` and the metric specified in `fun_control`.

1. First, the method `HyperTorch().fun_torch` is called.
2. `fun_torc()`, which is implemented in the file `hypertorch.py`, calls `evaluate_hold_out()` as follows:

```
df_eval, _ = evaluate_hold_out(
    model,
    train_dataset=fun_control["train"],
    shuffle=self.fun_control["shuffle"],
    loss_function=self.fun_control["loss_function"],
    metric=self.fun_control["metric_torch"],
    device=self.fun_control["device"],
    show_batch_interval=self.fun_control["show_batch_interval"],
    path=self.fun_control["path"],
    task=self.fun_control["task"],
    writer=self.fun_control["writer"],
    writerId=config_id,
)
```

Note: Only the data set `fun_control["train"]` is used for training and validation. It is used in `evaluate_hold_out` as follows:

```
trainloader, valloader = create_train_val_data_loaders(
    dataset=train_dataset, batch_size=batch_size_instance, shuffle=shuffle
)
```

`create_train_val_data_loaders()` splits the `train_dataset` into `trainloader` and `valloader` using `torch.utils.data.random_split()` as follows:

```
def create_train_val_data_loaders(dataset, batch_size, shuffle, num_workers=0):
    test_abs = int(len(dataset) * 0.6)
    train_subset, val_subset = random_split(dataset, [test_abs, len(dataset) - test_abs])
    trainloader = torch.utils.data.DataLoader(
        train_subset, batch_size=int(batch_size), shuffle=shuffle, num_workers=num_workers
    )
    valloader = torch.utils.data.DataLoader(
```

```

        val_subset, batch_size=int(batch_size), shuffle=shuffle, num_workers=num_workers
    )
    return trainloader, valloader

```

The optimizer is set up as follows:

```

optimizer_instance = net.optimizer
lr_mult_instance = net.lr_mult
sgd_momentum_instance = net.sgd_momentum
optimizer = optimizer_handler(
    optimizer_name=optimizer_instance,
    params=net.parameters(),
    lr_mult=lr_mult_instance,
    sgd_momentum=sgd_momentum_instance,
)

```

3. `evaluate_hold_out()` sets the `net` attributes such as `epochs`, `batch_size`, `optimizer`, and `patience`. For each epoch, the methods `train_one_epoch()` and `validate_one_epoch()` are called, the former for training and the latter for validation and early stopping. The validation loss from the last epoch (not the best validation loss) is returned from `evaluate_hold_out`.
4. The method `train_one_epoch()` is implemented as follows:

```

def train_one_epoch(
    net,
    trainloader,
    batch_size,
    loss_function,
    optimizer,
    device,
    show_batch_interval=10_000,
    task=None,
):
    running_loss = 0.0
    epoch_steps = 0
    for batch_nr, data in enumerate(trainloader, 0):
        input, target = data
        input, target = input.to(device), target.to(device)
        optimizer.zero_grad()
        output = net(input)
        if task == "regression":

```

```

        target = target.unsqueeze(1)
        if target.shape == output.shape:
            loss = loss_function(output, target)
        else:
            raise ValueError(f"Shapes of target and output do not match:
                               {target.shape} vs {output.shape}")
    elif task == "classification":
        loss = loss_function(output, target)
    else:
        raise ValueError(f"Unknown task: {task}")
    loss.backward()
    torch.nn.utils.clip_grad_norm_(net.parameters(), max_norm=1.0)
    optimizer.step()
    running_loss += loss.item()
    epoch_steps += 1
    if batch_nr % show_batch_interval == (show_batch_interval - 1):
        print(
            "Batch: %5d. Batch Size: %d. Training Loss (running): %.3f"
            % (batch_nr + 1, int(batch_size), running_loss / epoch_steps)
        )
        running_loss = 0.0
    return loss.item()

```

5. The method `validate_one_epoch()` is implemented as follows:

```

def validate_one_epoch(net, valloader, loss_function, metric, device, task):
    val_loss = 0.0
    val_steps = 0
    total = 0
    correct = 0
    metric.reset()
    for i, data in enumerate(valloader, 0):
        # get batches
        with torch.no_grad():
            input, target = data
            input, target = input.to(device), target.to(device)
            output = net(input)
            # print(f"target: {target}")
            # print(f"output: {output}")
            if task == "regression":
                target = target.unsqueeze(1)

```

```

        if target.shape == output.shape:
            loss = loss_function(output, target)
        else:
            raise ValueError(f"Shapes of target and output
                             do not match: {target.shape} vs {output.shape}")
        metric_value = metric.update(output, target)
    elif task == "classification":
        loss = loss_function(output, target)
        metric_value = metric.update(output, target)
        _, predicted = torch.max(output.data, 1)
        total += target.size(0)
        correct += (predicted == target).sum().item()
    else:
        raise ValueError(f"Unknown task: {task}")
    val_loss += loss.cpu().numpy()
    val_steps += 1
loss = val_loss / val_steps
print(f"Loss on hold-out set: {loss}")
if task == "classification":
    accuracy = correct / total
    print(f"Accuracy on hold-out set: {accuracy}")
# metric on all batches using custom accumulation
metric_value = metric.compute()
metric_name = type(metric).__name__
print(f"{metric_name} value on hold-out data: {metric_value}")
return metric_value, loss

```

18.14.1.1 Description of the "test_hold_out" Setting

It uses the loss function specified in `fun_control` and the metric specified in `fun_control`.

1. First, the method `HyperTorch().fun_torch` is called.
2. `fun_torch()` calls `spotPython.torch.traintest.evaluate_hold_out()` similar to the "train_hold_out" setting with one exception: It passes an additional test data set to `evaluate_hold_out()` as follows:

```
test_dataset=fun_control["test"]
```

`evaluate_hold_out()` calls `create_train_test_data_loaders` instead of `create_train_val_data_loaders`: The two data sets are used in `create_train_test_data_loaders` as follows:

```

def create_train_test_data_loaders(dataset, batch_size, shuffle, test_dataset,
    num_workers=0):
    trainloader = torch.utils.data.DataLoader(
        dataset, batch_size=int(batch_size), shuffle=shuffle,
        num_workers=num_workers
    )
    testloader = torch.utils.data.DataLoader(
        test_dataset, batch_size=int(batch_size), shuffle=shuffle,
        num_workers=num_workers
    )
    return trainloader, testloader

```

3. The following steps are identical to the "train_hold_out" setting. Only a different data loader is used for testing.

18.14.1.2 Detailed Description of the "train_cv" Setting

It uses the loss function specified in `fun_control` and the metric specified in `fun_control`.

1. First, the method `HyperTorch().fun_torch` is called.
2. `fun_torch()` calls `spotPython.torch.traintest.evaluate_cv()` as follows (Note: Only the data set `fun_control["train"]` is used for CV.):

```

df_eval, _ = evaluate_cv(
    model,
    dataset=fun_control["train"],
    shuffle=self.fun_control["shuffle"],
    device=self.fun_control["device"],
    show_batch_interval=self.fun_control["show_batch_interval"],
    task=self.fun_control["task"],
    writer=self.fun_control["writer"],
    writerId=config_id,
)

```

3. In `evaluate_cv()`, the following steps are performed: The optimizer is set up as follows:

```

optimizer_instance = net.optimizer
lr_instance = net.lr
sgd_momentum_instance = net.sgd_momentum
optimizer = optimizer_handler(optimizer_name=optimizer_instance,
    params=net.parameters(), lr_mult=lr_mult_instance)

```

`evaluate_cv()` sets the `net` attributes such as `epochs`, `batch_size`, `optimizer`, and `patience`. CV is implemented as follows:

```
def evaluate_cv(
    net,
    dataset,
    shuffle=False,
    loss_function=None,
    num_workers=0,
    device=None,
    show_batch_interval=10_000,
    metric=None,
    path=None,
    task=None,
    writer=None,
    writerId=None,
):
    lr_mult_instance = net.lr_mult
    epochs_instance = net.epochs
    batch_size_instance = net.batch_size
    k_folds_instance = net.k_folds
    optimizer_instance = net.optimizer
    patience_instance = net.patience
    sgd_momentum_instance = net.sgd_momentum
    removed_attributes, net = get_removed_attributes_and_base_net(net)
    metric_values = {}
    loss_values = {}
    try:
        device = getDevice(device=device)
        if torch.cuda.is_available():
            device = "cuda:0"
            if torch.cuda.device_count() > 1:
                print("We will use", torch.cuda.device_count(), "GPUs!")
                net = nn.DataParallel(net)
        net.to(device)
        optimizer = optimizer_handler(
            optimizer_name=optimizer_instance,
            params=net.parameters(),
            lr_mult=lr_mult_instance,
            sgd_momentum=sgd_momentum_instance,
        )
        kfold = KFold(n_splits=k_folds_instance, shuffle=shuffle)
```

```

for fold, (train_ids, val_ids) in enumerate(kfold.split(dataset)):
    print(f"Fold: {fold + 1}")
    train_subsampler = torch.utils.data.SubsetRandomSampler(train_ids)
    val_subsampler = torch.utils.data.SubsetRandomSampler(val_ids)
    trainloader = torch.utils.data.DataLoader(
        dataset, batch_size=batch_size_instance,
        sampler=train_subsampler, num_workers=num_workers
    )
    valloader = torch.utils.data.DataLoader(
        dataset, batch_size=batch_size_instance,
        sampler=val_subsampler, num_workers=num_workers
    )
    # each fold starts with new weights:
    reset_weights(net)
    # Early stopping parameters
    best_val_loss = float("inf")
    counter = 0
    for epoch in range(epochs_instance):
        print(f"Epoch: {epoch + 1}")
        # training loss from one epoch:
        training_loss = train_one_epoch(
            net=net,
            trainloader=trainloader,
            batch_size=batch_size_instance,
            loss_function=loss_function,
            optimizer=optimizer,
            device=device,
            show_batch_interval=show_batch_interval,
            task=task,
        )
        # Early stopping check. Calculate validation loss from one epoch:
        metric_values[fold], loss_values[fold] = validate_one_epoch(
            net, valloader=valloader, loss_function=loss_function,
            metric=metric, device=device, task=task
        )
        # Log the running loss averaged per batch
        metric_name = "Metric"
        if metric is None:
            metric_name = type(metric).__name__
            print(f"{metric_name} value on hold-out data:
                  {metric_values[fold]}")

```



```

        if writer is not None:
            writer.add_scalars(
                "evaluate_cv fold:" + str(fold + 1) +
                ". Train & Val Loss and Val Metric" + writerId,
                {"Train loss": training_loss, "Val loss":
                 loss_values[fold], metric_name: metric_values[fold]},
                epoch + 1,
            )
            writer.flush()
        if loss_values[fold] < best_val_loss:
            best_val_loss = loss_values[fold]
            counter = 0
            # save model:
            if path is not None:
                torch.save(net.state_dict(), path)
        else:
            counter += 1
            if counter >= patience_instance:
                print(f"Early stopping at epoch {epoch}")
                break

    df_eval = sum(loss_values.values()) / len(loss_values.values())
    df_metrics = sum(metric_values.values()) / len(metric_values.values())
    df_preds = np.nan
except Exception as err:
    print(f"Error in Net_Core. Call to evaluate_cv() failed. {err=},
          {type(err)=}")
    df_eval = np.nan
    df_preds = np.nan
add_attributes(net, removed_attributes)
if writer is not None:
    metric_name = "Metric"
    if metric is None:
        metric_name = type(metric).__name__
    writer.add_scalars(
        "CV: Val Loss and Val Metric" + writerId,
        {"CV-loss": df_eval, metric_name: df_metrics},
        epoch + 1,
    )
    writer.flush()
return df_eval, df_preds, df_metrics

```

4. The method `train_fold()` is implemented as shown above.

5. The method `validate_one_epoch()` is implemented as shown above. In contrast to the hold-out setting, it is called for each of the k folds. The results are stored in a dictionaries `metric_values` and `loss_values`. The results are averaged over the k folds and returned as `df_eval`.

18.14.1.3 Detailed Description of the "test_cv" Setting

It uses the loss function specified in `fun_control` and the metric specified in `fun_control`.

1. First, the method `HyperTorch().fun_torch` is called.
2. `fun_torch()` calls `spotPython.torch.traintest.evaluate_cv()` as follows:

```
df_eval, _ = evaluate_cv(  
    model,  
    dataset=fun_control["test"],  
    shuffle=self.fun_control["shuffle"],  
    device=self.fun_control["device"],  
    show_batch_interval=self.fun_control["show_batch_interval"],  
    task=self.fun_control["task"],  
    writer=self.fun_control["writer"],  
    writerId=config_id,  
)
```

Note: The data set `fun_control["test"]` is used for CV. The rest is the same as for the "train_cv" setting.

18.14.1.4 Detailed Description of the Final Model Training and Evaluation

There are two methods that can be used for the final evaluation of a Pytorch model:

1. "train_tuned and
2. "test_tuned".

`train_tuned()` is just a wrapper to `evaluate_hold_out` using the `train` data set. It is implemented as follows:

```
def train_tuned(  
    net,  
    train_dataset,  
    shuffle,  
    loss_function,  
    metric,
```

```

        device=None,
        show_batch_interval=10_000,
        path=None,
        task=None,
        writer=None,
    ):
        evaluate_hold_out(
            net=net,
            train_dataset=train_dataset,
            shuffle=shuffle,
            test_dataset=None,
            loss_function=loss_function,
            metric=metric,
            device=device,
            show_batch_interval=show_batch_interval,
            path=path,
            task=task,
            writer=writer,
        )

```

The `test_tuned()` procedure is implemented as follows:

```

def test_tuned(net, shuffle, test_dataset=None, loss_function=None,
               metric=None, device=None, path=None, task=None):
    batch_size_instance = net.batch_size
    removed_attributes, net = get_removed_attributes_and_base_net(net)
    if path is not None:
        net.load_state_dict(torch.load(path))
        net.eval()
    try:
        device = getDevice(device=device)
        if torch.cuda.is_available():
            device = "cuda:0"
            if torch.cuda.device_count() > 1:
                print("We will use", torch.cuda.device_count(), "GPUs!")
                net = nn.DataParallel(net)
        net.to(device)
        valloader = torch.utils.data.DataLoader(
            test_dataset, batch_size=int(batch_size_instance),
            shuffle=shuffle,
            num_workers=0
        )

```

```

metric_value, loss = validate_one_epoch(
    net, valloader=valloader, loss_function=loss_function,
    metric=metric, device=device, task=task
)
df_eval = loss
df_metric = metric_value
df_preds = np.nan
except Exception as err:
    print(f"Error in Net_Core. Call to test_tuned() failed. {err=},
          {type(err)=}")
    df_eval = np.nan
    df_metric = np.nan
    df_preds = np.nan
add_attributes(net, removed_attributes)
print(f"Final evaluation: Validation loss: {df_eval}")
print(f"Final evaluation: Validation metric: {df_metric}")
print("-----")
return df_eval, df_preds, df_metric

```

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