

A review of R neural network packages (with NNbenchmark): accuracy and ease of use

by Salsabila Mahdi, Akshaj Verma, Christophe Dutang, Patrice Kiener, John C. Nash

Abstract

For the last 30 years, neural networks have evolved from an academic topic to a common tool in scientific computing. Following this trend, CRAN has chosen to host many packages that claim to provide neural network modeling. Our count in May 2020 is roughly 70 packages. How accurate and reliable are these packages and their documentation? Are there packages that perform better in terms of accuracy? Are some better suited to beginners while others require expert knowledge? Do these packages provide the features found in some dedicated proprietary software?

This paper is, to our knowledge, the first attempt to test this rather large number of packages against a few datasets with different levels of complexity, and to benchmark and rank them with certain metrics. We have restricted our evaluation to regression algorithms applied on the one-hidden layer perceptron and ignored those for classification or other specialized purposes. This left us with 49 package::algorithm pairs in 2019 and 60 package::algorithm pairs in 2020. The criteria used in our benchmark were: (i) the accuracy, i.e. the ability to find the global minima on 13 datasets, measured by the Root Mean Square Error (RMSE) in a limited number of iterations; (ii) the speed of the training algorithm; (iii) the availability of helpful utilities; (iv) and the quality of the documentation.

All package::algorithm pairs were given a score for each criterion and ranked in a global table. Overall, 15 package::algorithm pairs are considered accurate and reliable and can be recommended for daily usage. 45 algorithms should be avoided as they are either less accurate, slow, difficult to handle, or have poor or no documentation.

Our codes, templates, and the NNbenchmark package used to test each package::algorithm pair are publicly available at the address <https://github.com/pkR-pkR/NNbenchmark>. These can be used by the package authors and others to verify the metrics and eventually improve their own package or code. Finally, we provide some hints and features to guide the development of an idealized neural network package for R.

Introduction

(PK) For the last 30 years, neural networks have evolved from an academic topic to a common tool in scientific computing. As a convenience in the general conversation, the same term is used in a generic manner (for a shortcut to) for different model structures and applications: multilayer perceptron for regression, multilayer perceptron for classification, multilayer perceptron for specialized applications (mixture of models, conditional distribution, etc), recurrent neural network for autoregressive time series (NARMAX models), convolutional neural networks for dimension reduction and pattern recognition, deep neural networks for image or voice recognition.

Most of the above types of neural networks can be found in R packages hosted on CRAN but without any warranty about the quality or the accuracy of the calculation, since CRAN has no tools to check them. Package users have to believe package authors who are assumed to have selected the best algorithms and tuned them with the appropriate hyperparameters. This is rather problematic with neural networks as many poor algorithms have been mentioned in the literature, and are probably implemented in a few packages.

The goal of this paper is to verify the accuracy and the ease of use (including the quality of the documentation) of the packages hosted on CRAN that supply the most common neural network structure + algorithm, i.e. the multilayer perceptron for regression purpose.

(SB) The R Project for Statistical Computing (www.r-project.org), as any opensource platform, relies on its contributors to keep it up to date. Neural networks, based on the brain's own connections system, are a class of models in the growing field of machine learning for which R has a number of tools. Previously, neural networks could be considered more theory than practice, partly because the algorithms used are computationally demanding.

A neural network algorithm requires complicated calculations to improve the model control parameters. As with other optimization problems, the gradient of the chosen cost function that indicates the lack of suitability of the model is sought. This lets us improve the model by changing the parameters in the negative gradient direction. Parameters for the model are generally obtained using part of the available data (a training set) and tested on the remaining data. Modern software allows much of this work, including approximation of the gradient, to be carried out without a large effort by the user.

This process can generally be made more efficient if we can also approximate second derivatives of the cost function, allowing us to use its curvature via the Hessian matrix. There are a large number of approaches, of which quasi-Newton algorithms are perhaps the most common and useful. Within this group, methods based on the Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm for updating the Hessian approximation (or its inverse) provide several well-known examples. In conducting this study, we believed that these second-order algorithms would perform better than first-order methods.

Regardless of our belief, we wished to be able to conduct a thorough examination of these training algorithms in R. There are many packages, but barely any information to allow comparison. Our work, reported here, aims to provide a framework for benchmarking neural network packages. We restrict our examination to packages for R, and in this report focus on those that provide neural networks of the perceptron type, that is, one input layer, one normalized layer, one hidden layer with a nonlinear activation function that is usually $\tanh()$, and one output layer.

Methodology

??JN: *****

In working on material below, I think we need to provide some explanation of goals - What does "convergence" mean in our context? - What do we mean by RMSE, other measures? Should define here for later use. - What do we mean by "performance"? Other goals?

Our research process was divided into 3 phases.

Phase 1 - Preparation

Datasets => NEED TO BE FINISHED??

All the datasets we use cannot generally be modeled using a non-iterative calculation such as Ordinary Least Squares. Varying levels of difficulty in modeling the different data sets are intended to allow us to further classify different algorithms and the packages that implement them. Sonja Surjanovic and Derek Bingham of Simon Fraser University created a useful website from which three of the multivariate datasets were drawn. We note the link, name and difficulty level of the three datasets:

- <http://www.sfu.ca/~ssurjano/fried.html> (Friedman - average)
- <http://www.sfu.ca/~ssurjano/dettep10curv.html> (Dette - medium)
- <http://www.sfu.ca/~ssurjano/ishigami.html> (Ishigami - high)

The other multivariate dataset, Ref153, was taken from ...

Three of the univariate datasets we used were taken from a website of the US National Institute for Standards and Technology (NIST): <https://www.itl.nist.gov/div898/strd/>

`nls/nls_main.shtml`. (Gauss1 - low; Gauss2 - low; Gauss3 - average)

Univariate datasets Dmod1, Dmod2 are from ...

Dreyfus1 is a pure neural network which has no error. This can make it difficult for algorithms that assume an error exists. Dreyfus2 is Dreyfus1 with errors. NeuroOne from ...
Wood ...

Packages

Using **RWsearch** (Kiener, 2020) we sought all were able to automate the process. All packages that have “neural network” as a keyword in the package title or in the package description were included. Packages **nlsr**, **minpack.lm**, **caret** were added because ...

Phase 2 - Review of packages and development of a benchmarking template

From documentation and example code, we learned that not all packages selected by the automated search fit the scope of our research. Some have no function to generate neural networks. They are simply meta-packages. Others were not regression neural networks of the perceptron type or were only intended for very specific purposes.

Templates for Testing Accuracy and Speed => TO REVISE AFTER 2020 CODE

As we inspected the packages, we developed a template for benchmarking. The structure of this template (for each package) is as follows:

- (1) Set up the test environment - loading of packages, setting working directory and options;
- (2) Summary of datasets;
- (3) Loop over datasets: (a) setting parameters for a specific dataset (b) selecting benchmark options (c) training a neural network with a tuned functions for each package (d) calculation of RMSE and MAE (??definition, reference) (e) plot each training over one initial graph, then plot the best result (f) add results to the appropriate existing record (*.csv file) and (g) clear the environment for next loop; and
- (4) Clearing up the environment for the next package. (5) It is optional to print warnings.

To simplify this process, we developed tools in the NNbenchmark package, of which the first version was created as part of the 2019 GSoC activity and later refined in the 2020 initiative. The package repository is <https://github.com/pkR-pkR/NNbenchmark>, with package templates in <https://github.com/pkR-pkR/NNbenchmarkTemplates>.

Metrics for Ease of Use

We decided ease of use based on what we considered a user would need when using a neural network package for nonlinear regression, namely, utility functions and sufficient documentation.

- (1) Utilities (1 star)
 - (a) a predict function exists
 - (b) scaling capabilities exist
- (2) Sufficient documentation (2 stars)
 - (a) the existence of useful example/vignette (1 star)
 - clear, with regression = 2 points
 - unclear, examples use iris or are for classification only = 1 point
 - no examples = 0 points
 - (b) input/output is clearly documented, e.g., what values are expected and returned by a function (1 star)
 - clear input and output = 2 points
 - only one is clear = 1 point

- both are not documented = 0 points

For a total of 0 to 3 stars.

Phase 3 - Collection of and analysis of results

Results collection

Looping over the datasets using each package template, we collected results in the relevant package directories in the templates repository.

Analysis

To rank the how well a package converged and its speed, we developed the following method:

1. The results datasets are loaded into the R environment as one large list. The dataset names, package:algorithm names and all 10 run numbers, durations, and RMSE are extracted from that list
2. For the duration score (DUR), the duration is averaged by dataset. 3 criteria for the RMSE score by dataset are calculated:
 - a. The minimum value of RMSE for each package:algorithm as a measure of their best performance
 - b. The median value of RMSE for each package:algorithm as a measure of their average performance, without the influence of outliers
 - c. The spread of the RMSE values for each package which is measured by the difference between the median and the minimum RMSE (d51)
3. Then, the ranks are calculated for every dataset and the results are merged into one wide dataframe.
 - a. The duration rank only depends on the duration.
 - b. For minimum RMSE values, ties are decided by duration mean, then the RMSE median
 - c. For median RMSE values, ties are decided by the RMSE minimum, then the duration mean
 - d. The d51 rank only depends on itself
4. A global score for all datasets is found by a sum of the ranks (of duration, minimum RMSE, median RMSE, d51 RMSE) of each package:algorithm for each dataset
5. The final table is the result of ranking by the global minimum RMSE scores for each package:algorithm
6. In addition to the previous metrics, two other convergence metrics have been considered: the Mean Absolute Error (MAE) and the Worst Absolute Error (WAE), see Appendix. The ranking on those two metrics may help distinguish packages with close RMSE values. However, we do not choose the MAE for overall ranking as there is no consensus in the literature, see e.g. (Willmott and Matsuura, 2005; Chai and Draxler, 2014).

To rank how easy or not a package was to use (TO BE DISCUSSED FURTHER): - Functionality (util): scaling, input, output, trace - Documentation (docs): examples, structure/functions, vignettes

Results

Tables (NOTE: FINAL MEASURE FOR CONVERGENCE - RMSE RANKS? OR A COMBINATION OF OTHER MEASURES? As in Christophe's recent email: L1 MAE(), L2 RMSE(), Linfinity (WAE)) -> see Appendix

(ALSO: THE FOLLOWING IS SIMPLY ALPHABETIC LIST FOR ALL TESTED, I WILL DIVIDE THE TABLE INTO 4: 2nd ORDER always recommended, 1st ORDER recommended, 1st ORDER not recommended, untested packages)

Table 1: Review of Tested Packages

No	Package::Function	Algorithm	RMSE	DUR	UTIL	DOCS
1	AMORE ::train	1. ADAPTgd 2. ADAPTgdwm 3. BATCHgd 4. BATCHgdwm				
2	ANN2 ::neuralnetwork	5. adam 6. rmsprop 7. sgd				
3	automl ::automl_train_manual	8. trainwgrad.adam 9. trainwgrad.RMSprop 10. trainwpso				
4	brnn ::brnn	11. Gauss-Newton				
5	CaDENCE ::cadence.fit	12. optim(BFGS) 13. pso::psoptim 14. Rprop				
6	caret ::avNNet	15. nnet::optim(BFGS)				
7	deepdive ::deepnet	16. adam 17. gradientDescent 18. momentum 19. rmsProp				
8	deepnet ::nn.train	20. BP				
9	elmNNRcpp ::elm_train	21. ELM				
10	ELMR ::OSelm_train.formula	22. ELM				
11	EnsembleBase ::Regression.Batch.Fit	23. nnet::optim(BFGS)				
12	h2o ::deeplearning	24.				
13	keras ::fit	25. adadelta 26. adagrad 27. adam 28. adamax 29. nadam 30. rmsprop 31. sgd				
14	MachineShop ::fit	32. nnet::optim(BFGS)				
15	minpack.lm ::nlsLM	33. LM				
16	monmlp ::fit monmlp ::fit	34. BFGS 35. Nelder-Mead				
17	neuralnet :: ::neuralnet	36. backprop 37. rprop- 38. rprop+ 39. sag 40. slr 41. NashLM				
18	nlsr ::nlxb	42. optim(BFGS)				
19	nnet ::nnet	43. nlm()				
20	qrnn ::qrnn.fit	45. nnet::optim(BFGS)				
21	radiant.model ::radiant.model	46. nnet::optim(BFGS)				
22	rminer ::fit	47. BackpropBatch 48. BackpropChunk 49. BackpropMomentum 50. BackpropWeightDecay 51. Quickprop 52. Rprop 53. SCG 54. Std-Backpropagation				
23	RSNNS :: RSNNS :: RSNNS :: RSNNS :: RSNNS :: RSNNS :: RSNNS :: RSNNS ::	55.				
24	snnR	56. BFGS				
25	traineR	57. CG				
26	validann :: validann :: validann :: validann :: validann ::	58. L-BFGS-B 59. Nelder-Mead 60. SANN				

(THE FOLLOWING IS JUST AN ALPHABETICALLY ORDERED LIST OF CURRENTLY UNTESTED PACKAGES)

Table 2: Review of Ommitted Packages

No	Name (package)	Category	Comment
1	appnn	AP	This package provides a feed forward neural network to predict the amyloidfogenicity propensity of polypeptide sequences
2	autoencoder	AP	
3	BNN	RE*	
4	Buddle	RE**	(errors) even performance on examples is bad
5	cld2	00	
6	cld3	AP	
7	condmixt	AP	
8	deep	CL	
9	DALEX2	00	removed keyword, included in 2019
10	DamiaNN	RE**	(errors) exported functions, still doesn't work
11	DChaos	??	removed keyword for some reason, need to check out!
12	deepNN	RE**	(errors) I/O weird, ragged vector array
13	DNMF	AP	
14	evclass	CL	
15	gamlss.add	RE	there is some code but dist not appropriate
16	gcForest	00	
17	GMDH	TS	
18	GMDH2	CL	
19	GMDHreg	RE*	
20	grnn	RE**	
21	hybridEnsemble	??	
22	isingLenzMC	AP	
23	leabRa	??	
24	learNN	??	
25	LilRhino	AP	
26	neural	CL	
27	NeuralNetTools	UT	tools for neural networks
28	NeuralSens	UT	tools for neural networks
29	NlinTS	TS	Time Series
30	nnetpredint	UT	confidence intervals for NN
31	nnfor	TS	Times Series, uses neuralnet
32	nntrf	UT	
33	onnx		provides an open source format
34	OptimClassifier		choose classifier parameters, nnet
35	OSTSC		solving oversampling classification
36	passt		
36	pnn		Probabilistic
37	polyreg		polyregression as alternative to NN
38	predictoR		shiny interface, neuralnet
39	ProcData		
40	QuantumOps		classifies MNIST, Schuld (2018), removed keyword, in 2019
41	quarrint		specified classifier for quarry data
42	rasclass		classifier for raster images, nnet?
43	rcane		
44	regressoR		a manual rich version of predictoR
45	rnn		Recurrent
46	RTextTools		
47	ruta		
48	simpleNeural		
49	softmaxreg		
50	Sojourn.Data		sojourn Accelerometer methods, nnet?
51	spnn		classifier, probabilistic
52	studyStrap		
53	TeachNet		classifier, selfbuilt, slow
54	tensorflow		
55	tfestimators		
56	trackden		classifier for particle tracking
57	TrafficBDE	RE*	
58	tsfgrnn		

Discussion and Recommendations

The following is a list of packages we included in this study, with brief descriptions.

1. **AMORE** (Limas et al., 2020),
2. **ANN2** (Lammers, 2020),
3. **appnn** (Família et al., 2015),
4. **autoencoder** (Dubossarsky and Tyshetskiy, 2015),
5. **automl** (Boulangé, 2020),
6. **BNN** (Jia, 2018),
7. **brnn** (Rodriguez and Gianola, 2020),
8. **Buddle** (Kim, 2020),
9. **CaDENCE** (Cannon, 2017a),
10. **cld2** (Ooms, 2018),
11. **cld3** (Ooms, 2020),
12. **condmixt** (Carreau, 2020),
13. **DamiaNN** (Siniakowicz, 2016),
14. **deep** (Mayer, 2019),
15. **deepdive** (Balakrishnan, 2020),
16. **deepnet** (Rong, 2014),
17. **deepNN** (Taylor, 2020),
18. **DNMF** (Jia and Zhang, 2015),
19. **elmNNRcpp** (Mouselimis and Gosso, 2020),
20. **ELMR** (Petrozziello, 2015),
21. **EnsembleBase** (Mahani and Sharabiani, 2016),
22. **evclass** (Denoeux, 2017),
23. **gamlss.add** (Stasinopoulos et al., 2020),
24. **gcForest** (Jing, 2018),
25. **GMDH** (Dag and Yozgatligil, 2016),
26. **GMDH2** (Dag et al., 2019),
27. **GMDHreg** (Tilve, 2020),
28. **gnn** (Hofert and Prasad, 2020),
29. **grnn** (Chasset, 2013a),
30. **h2o** (LeDell et al., 2020),
31. **hybridEnsemble** (Ballings et al., 2015),
32. **isingLenzMC** (Suzen, 2016),
33. **keras** (Allaire and Chollet, 2020),

34. **kerasR** (Arnold, 2017),
35. **leabRa** (Titz, 2017),
36. **learNN** (Quast, 2015),
37. **LilRhino** (Barton, 2019),
38. **minpack.lm** (Elzhov et al., 2016),
39. **MachineShop** (Smith, 2020),
40. **monmlp** (Cannon, 2017b),
41. **neural** (Nagy, 2014),
42. **neuralnet** (Fritsch et al., 2019),
43. **NeuralNetTools** (Beck, 2018),
44. **NeuralSens** (Portela González et al., 2020),
45. **NlinTS** (Hmamouche, 2020),
46. **nlsr** (Nash and Murdoch, 2019),
47. **nnet** (Ripley, 2020),
48. **nnetpredint** (Ding, 2015),
49. **nnfor** (Kourentzes, 2019),
50. **nntrf** (Aler and Valls, 2020),
51. **nnli2bRcpp** (Nikolaidis, 2020),
52. **onnx** (Tang and ONNX Authors, 2018),
53. **OptimClassifier** (Perez-Martin et al., 2020),
54. **OSTSC** (Dixon et al., 2017),
55. **pnn** (Chasset, 2013b),
56. **polyreg** (Matloff et al., 2020),
57. **predictoR** (with contributions from Diego Jimenez A. and D., 2020),
58. **qrnn** (Cannon, 2019),
59. **QuantumOps** (Resch, 2020),
60. **quarrint** (Barthelemy et al., 2016),
61. **radiant.model** (Nijs, 2020),
62. **rasclass** (Wiesmann and Quinn, 2016),
63. **rcane** (Suresh et al., 2018),
64. **regressoR** (Rodriguez R., 2019),
65. **rminer** (Cortez, 2020),
66. **rnn** (Quast and Fichou, 2020),
67. **RSNNS** (Bergmeir, 2019),
68. **ruta** (Charte et al., 2019),

69. [simpleNeural](#) (Dernoncourt, 2020),
70. [snnR](#) (Wang et al., 2017),
71. [softmaxreg](#) (Ding, 2016),
72. [Sojourn.Data](#) (Hibbing and Lyden, 2019),
73. [spnn](#) (Ebrahimi, 2020),
74. [TeachNet](#) (Steinbuss, 2018),
75. [tensorflow](#) (Allaire and Tang, 2020),
76. [tfestimators](#) (Allaire et al., 2018),
77. [trackdem](#) (Bruijning et al., 2020),
78. [TrafficBDE](#) (Chatzopoulou et al., 2018),
79. [tsensembler](#) (Cerqueira et al., 2017),
80. [validann](#) (Humphrey, 2017),
81. [zFactor](#) (Reyes, 2019).
- 82.
- 83.
- 84.
- 85.
- 86.
- 87.
- 88.

A. Recommended: 2nd order algorithms Out of all the algorithms, these second algorithms generally performed better in terms of convergence despite being set to a much lower number of iterations, 200, than the first-order algorithms. Moreover, they performed better in terms of speed. The best in this class were. [minpack.lm](#) and. [nlshr](#), tied at rank number 1. The Levenberg-Marquardt (LM) algorithm used is fast and converges well. `stats::nlm()` is used. However, these packages require a handwritten formula that may not be ideal for certain situations. A more popular package for neural networks is `nnet`. This might be because it is part of base R. It implements the BFGS algorithm with `stats::optim()`.

Ranked directly after are some packages that depend on `nnet` or use the same functions. They differ in how well they decide initial parameters. `rminer` (rank 4), `MachineShop` (rank 5), and `radiant.model` (rank 7) use `nnet`. Note, `radiant.model` has its iterations set to 10000, which originally made it slower yet converge better. We used a modified version of the package. At rank 6 is `validann`'s BFGS algorithm using `stats::optim()`. Its use of `optim`'s L-BFGS-B ranked at number 9 with `CaDENCE`'s use of `optim`'s BFGS.. [monmlp](#), from the same author as `CaDENCE` (Alex Cannon), uses the package. [optimx](#)'s BFGS (Nash and Varadhan, 2020).

Alex Cannon also implemented a quantile regression neural network in `qrnn` with `stats::nlm()`. It requires more iterations and is not as fast compared to the other second-order algorithms. However, it is a valuable implementation of quantile regression. Last but not least is [brnn](#)'s Gauss Newton algorithm which ranks at number 8. `brnn` is easy to use but does not converge as well due to a hidden constraint: a missing first parameter. Furthermore, `brnn`'s algorithm minimizes the sum of squared errors and a penalty on parameters instead

of just the sum of squared errors. This may prevent parameters to get highly correlated, especially with an almost degenerated Jacobian matrix.

B. Recommended: 1st order algorithms validann optim CG -slow RSNNS SCG h2o back-propagation RSNNS Rprop ANN2 adam CaDENCE Rprop -SLOW deepnet BP AMORE ADAPTgdwm AMORE ADAPTgd ANN2 sgd automl trainwgrad ANN2 rmsprop RSNNS BackpropChunk RSNNS BackWeightDecay RSNNS Std_Backpropagation RSNNS Backprop-Momentum automl trainwpso validann optim NelderMead snnR Semi Smooth Newton RSNNS BackpropBatch validann optim SANN monmlp optimx Nelder Mead

C. Not recommended: 1st order algorithms <- DISCUSS CUTOFF By package ELMR, elmNNRcpp - fast ELM algorithms. Unfortunately, can't finetune, does not converge well. neuralnet: a large ammount of iterations, slow, erratic failures tensorflow: NOT EASY TO USE, subsequently keras, tfestimators, ruta ... user needs to understand the language However, advanced users might be able to highly specify a neural network to their needs (customization?)

By algorithm: neuralnet rprop+ neuralnet rprop- neuralnet slr - once ranked well with 100000 iterations AMORE BATCHgd CaDENCE pso psoptim - need to reconfigure? elmN-NNRcpp - fast, no iterations RSNNS Quickprop (?) AMORE BATCHgdwm tensorflow MomentumOptimizer tensorflow AdamOptimizer ELMR - fast, no iterations tensorflow GradientDescentOptimizer keras rmsprop keras adagrad keras sgd keras adadelta tensorflow AdagradOptimizer keras adam tensorflow FtrlOptimizer neuralnetwork sag tensorflow AdadeltaOptimizer neuralnet backprop - note, might not actually reflect standings, somehow from template to template the learning rate disappeared. Will fix this in future runs

D. Untested => TO DO - LIST

Conclusion => TO DO AFTER 2020 CODE

??JN: Can we start to put in some major findings? i.e., important positive findings, big negatives?

Positives (no particular order)

1. the existence of algorithms that converge well
2. nnet, which uses optim's BFGS, is already often chosen to represent neural networks for packages that are either a collection of independent machine learning algorithms, ensembles, or even applications in a field such as ...
3. the wide variety of neural networks available to users of R, from libraries of other programming languages to many different types of algorithms, hyperparameters, and uses

Negatives (no particular order)

1. bad documentation
2. the lack of packages that expand the number of unique second order algorithms. (Perhaps even the existence of what can be considered as repetitive packages?)
3. the lack of clear default values, or bad default values

Future work

As the field of neural networks continue to grow, there will always be more algorithms to validate. For current algorithms in R, our research should be extended to encompass more types of neural networks and their data formats (classifier neural networks, recurrent neural networks, and so on). Different rating schemes and different parameters for package functions can also be tried out.

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- The dreamed NN package: Recommendation to package authors
- Conclusion
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How do we proceed?

Appendix A

Consider a set of observations y_i and its corresponding predictions \hat{y}_i for $i = 1, \dots, n$. The three metrics used were:

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i|, RMSE = \frac{1}{n} \sqrt{\sum_{i=1}^n (y_i - \hat{y}_i)^2}, WAE = \frac{1}{n} \max_{i=1, \dots, n} |y_i - \hat{y}_i|.$$

These values represent the absolute, the squared and the maximum norm of residual vectors.

Salsabila Mahdi

Universitas Syiah Kuala

Jl. Syech Abdurrauf No.3, Aceh 23111, Indonesia

bila.mahdi@mhs.unsyiah.ac.id

Akshaj Verma

Manipal Institute of Technology

Manipal, Karnataka, 576104, India

akshajverma7@gmail.com

Christophe Dutang

University Paris-Dauphine, University PSL, CNRS, CEREMADE

Place du Maréchal de Lattre de Tassigny, 75016 Paris, France

dutang@ceremade.dauphine.fr

Patrice Kiener

InModelia

5 rue Malebranche, 75005 Paris, France

patrice.kiener@inmodelia.com

John C. Nash

Telfer School of Management, University of Ottawa

55 Laurier Avenue East, Ottawa, Ontario K1N 6N5 Canada

nashjc@uottawa.ca