

Time Series Methods in the R package **mlr**

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Abstract

The **mlr** package is a unified interface for machine learning tasks such as classification, regression, cluster analysis, and survival analysis. **mlr** handles the data pipeline of preprocessing, resampling, model selection, model tuning, ensembling, and prediction. This paper details new methods for developing time series models in **mlr**. It includes standard and novel tools such as autoregressive and LambertW transform data generating processes, fixed and growing window cross validation, and forecasting models in the context of univariate and multivariate time series. Examples from forecasting competitions will be given in order to demonstrate the benefits of a unified framework for machine learning and time series.

1 Introduction

There has been a rapid development in time series methods over the last 25 years [17] whereby time series models have not only become more common, but more complex. The R language [31] has several task views with compiling the packages available for forecasting, time series methods, and applied finance. However, the open source nature of R has left users without a standard framework. Many packages have their own sub-culture of style, syntax, and output. The **mlr** [5] package, short for Machine Learning in R, works to give a strong syntactic framework for the modeling pipeline. By automating many of the standard tools in machine learning such as preprocessing and cross validation, **mlr** reduces error from the user during the modeling process.

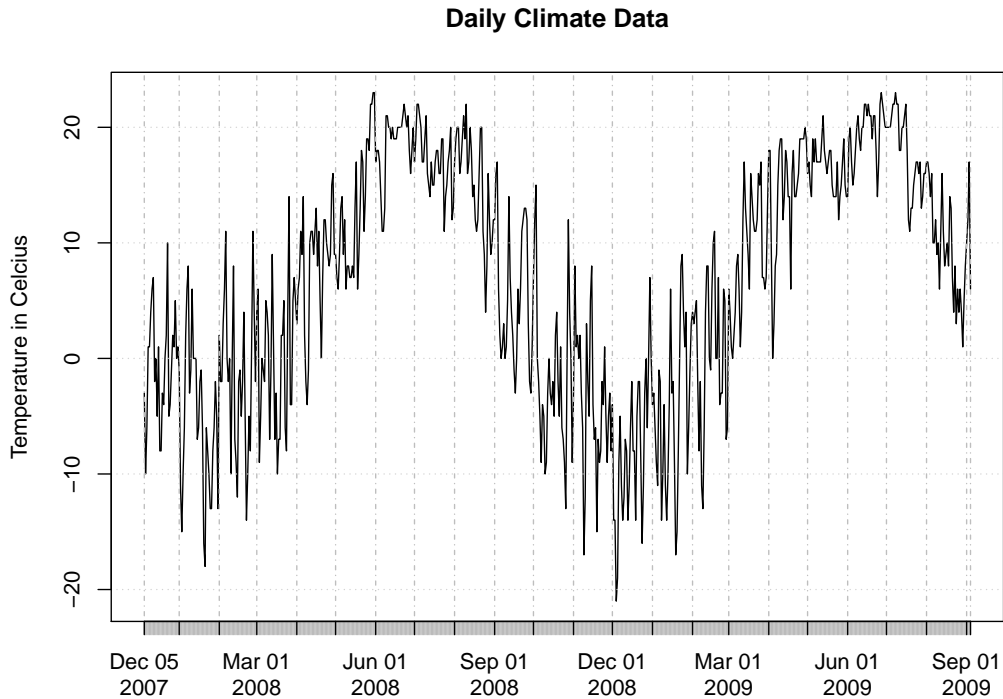
While there are some time series methods available in **caret** [13], development of forecasting models in **caret** is difficult due to computational constraints and design choices within the package. The highly modular structure of **mlr** makes it the best choice for implementing time series methods and models. This paper will show how using **mlr**'s strong syntactic structure allows for time series packages such as **forecast** [22], **rugarch** [14], and **BigVAR** [30] to use machine learning methodologies such as automated parameter tuning, data preprocessing, model blending, cross validation, performance evaluation, and parallel processing techniques for decreasing model build time.

2 Forecasting Example with the M4 Competition

Professional forecasters attempt to predict the future of a series based on its past values. Forecasting can be used in a wide range of tasks including forecasting stock prices, [19],

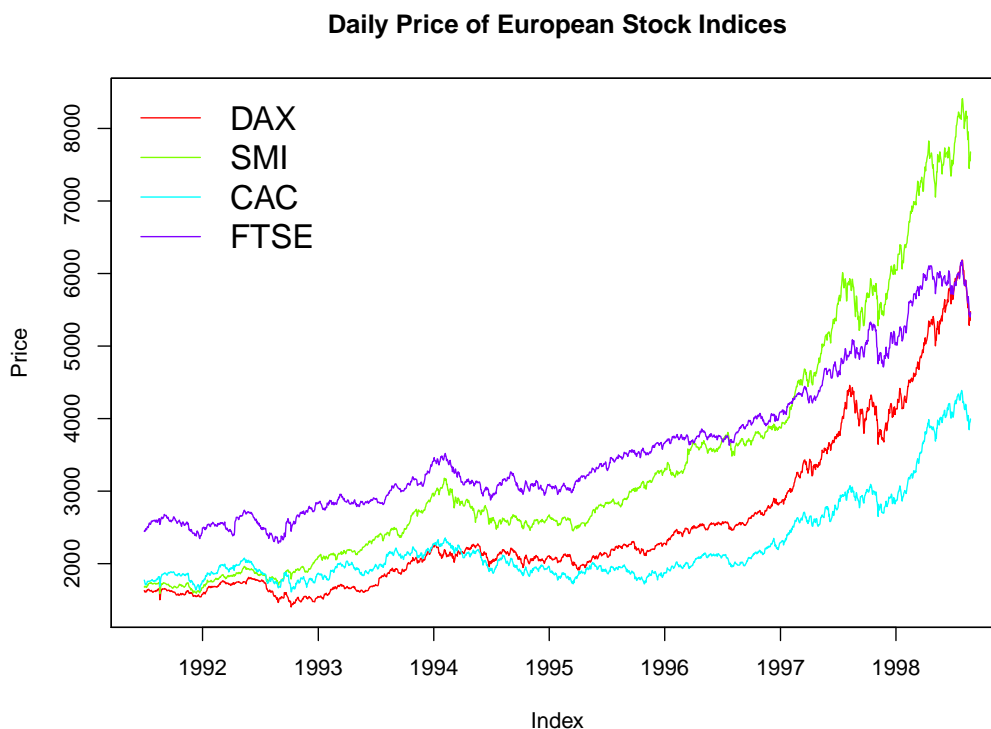
weather patterns [1], international conflicts [6], and earthquakes [38]. In order to evaluate **mlr**'s forecasting framework we need a large set of possible time series to make sure our methods generalize well.

The Makridakis competition [27] is a set of forecasting challenges organized by the International Institute of Forecasters and led by Spyros Makridakis to evaluate and compare the accuracy of forecasting methods. The most recent of the competitions, the M4 competition, contains 10,000 time series on a yearly, quarterly, monthly, and daily frequency in areas such as finance, macroeconomics, climate, microeconomics, and industry. To show examples of how **mlr**'s forecasting features works we will look at a particular climate series. The data is daily with the training subset starting on September 6th, 2007 and ending on September 5th, 2009 while the testing subset is from September 6th, 2009 to October 10th, 2009 for a total of 640 training periods and 35 test periods to forecast.



This series was chosen for its obvious seasonality and time features. Some series in M4 only contain 12 observations, which is not enough data to accurately train a model. The example data set should be large enough that the tuning method can take multiple windows of the data. We can see figure one is what most people imagine when they think of a time series. There is a clear seasonal time trend with individual points moving about the seasonal periods. The data can be found in the package **M4comp** [2] under sets **M4**[28] and **M4**[29].

For multivariate forecasting, we will use the EUSockMarkets data set from the **datasets** [32]. It contains a set of DAX, SMI, CAC, and FTSE European stock indices from July 1st, 1991 to August 24th, 1998 totaling 1828 training observations and 32 test observations.



Note that each stock index tends to follow a similar, but diverging, trend. This will be important to note when we perform windowing cross validation as it will let us see how well the models adapt to what appears to be nonstationary data.

3 Univariate and Multivariate Forecasting Tasks

4 Univariate Tasks

mlr uses the S3 object system to clearly define a predictive modeling task. Tasks contain the data and other relevant information such as the task id and which variable you are targeting for supervised learning problems. Forecasting tasks are handled in **mlr** by the function `makeForecastRegrTask()`. The forecasting task inherits most of its arguments from `makeRegrTask`, but has two noticeable differences in arguments.

data: Instead of a data frame, an `xts` object from `xts` [36] containing the time series.

frequency: An integer with the periodicity of the time series. For example, daily data with a weekly periodicity has a frequency of 7, daily data with a yearly periodicity has a frequency of 365, and weekly data with a yearly frequency has a periodicity of 52.

```

library(mlr)
climate.task = makeForecastRegrTask(id = "M4 Climate Data",
                                   data = m4.train,
                                   target = "target_var",
                                   frequency = 183L)

climate.task

## Task: M4 Climate Data
## Type: fcregr
## Target: target_var
## Observations: 640
## Dates:
##   Start: 2007-12-05
##   End:   2009-09-04
## Frequency: 183
## Features:
## numerics  factors  ordered
##         0         0         0
## Missings: FALSE
## Has weights: FALSE
## Has blocking: FALSE

```

Like a regression task, this records the type of the learning problem and basic information about the data set such as the start and end dates, frequency, and whether we have missing values. Note that there are zero features in our task because we only have a target variable, which the model itself will use to build features.

4.1 Multivariate Tasks

One common problem with forecasting is that it is difficult to use additional explanatory variables or forecast multiple targets that are dependent on one another. If we are at time t and want to forecast 10 periods in the future, we need to know the values of the explanatory variables at time $t + 10$, which is often not possible. A new set of models [30] which treats explanatory variables endogenously instead of exogenously allows us to forecast not only our target, but additional explanatory variables. This is done by treating all the variables as targets, making them endogeneous to the model. To use these models, we create a multivariate forecasting task. The function `makeMultiForecastRegrTask()` has the same arguments as `makeForecastRegrTask()` with one exception. The `target` argument can contain either a single target variable, multiple target variables, or `All` which treats all variables endogeneously.

```

mfcregr.univar.task = makeMultiForecastRegrTask(id = "bigvar",
                                                data = EuStockMarkets,
                                                target = "FTSE",
                                                frequency = 365L)

mfcregr.univar.task

## Task: bigvar

```

```
## Type: mfc regr
## Target: FTSE
## Observations: 1860
## Dates:
## Start: 1991-07-01 02:18:27
## End: 1998-08-24 20:18:27
## Frequency: 365
## Features:
## numerics factors ordered
##      3      0      0
## Missings: FALSE
## Has weights: FALSE
## Has blocking: FALSE
```

Like `makeForecastRegrTask()`, `mfc regr.univar.task` has the standard output, but notice now that there are three features. Alternatively, `mfc regr.all.task` contains multiple target values with no features. The difference between each of these multivariate tasks is that `mfc regr.univar.task` will act similar to `makeForecastRegrTask()`, giving the output, predictions, and even using the measures for univariate forecasting tasks. Both of these tasks will still forecast all of the underlying series, which allows us take exogeneous models and treat them endogeneously for n-step forecasts that use additional explanatory variables.

```
mfc regr.all.task = makeMultiForecastRegrTask(id = "bigvar",
                                              data = eu.train,
                                              target = "all",
                                              frequency = 365L)

mfc regr.all.task

## Task: bigvar
## Type: mfc regr
## Target: DAX SMI CAC FTSE
## Observations: 1828
## Dates:
## Start: 1991-07-01 02:18:27
## End: 1998-07-10 22:09:13
## Frequency: 365
## Features:
## numerics factors ordered
##      0      0      0
## Missings: FALSE
## Has weights: FALSE
## Has blocking: FALSE
```

5 Building and Tuning a forecast learner

5.1 Univariate Forecasting

The `makeLearner()` function provides a structured model building framework to the several forecasting models currently implemented in **mlr**. As an example, we will build the Trigonometric exponential smoothing state space model with Box-Cox transformation, ARMA errors, Trend and Seasonal Components (TBATS) [26].

TBATS is one of the most well known forecasting models and is available in **mlr** along with models such as BATS, ARIMA, ETS, several GARCH variants, and autoregressive neural networks. In addition, preprocessing features have been added to allow arbitrary supervised machine learning models to be used in the context of forecasting. To implement the TBATS model we use `makeLearner()`, supplying the class of learner, order, the number of steps to forecast, and any additional arguments to be passed to `tbats` for `forecast`.

```
tbats.mod = makeLearner("fcregr.tbats", use.box.cox = TRUE,
                        use.trend = TRUE,
                        seasonal.periods = TRUE, max.p = 60, max.q = 60,
                        stationary = FALSE, use.arma.errors = TRUE,
                        h = 35, predict.type = "response")
```

We can also supply a predict type for forecasting models to either receive point estimates (`response`) or point estimates with quantiles of confidence intervals (`quantile`). To train the model we simply call `train`, supplying the forecasting model and task. After training the model it's simple to get our forecasts by calling `predict()` with the test data, returning an object containing meta information for the forecasts along with the prediction and test data in columns `truth` and `response`, respectively.

```
train.tbats = train(learner = tbats.mod, task = climate.task)
train.tbats

## Model for learner.id=fcregr.tbats; learner.class=fcregr.tbats
## Trained on: task.id = M4 Climate Data; obs = 640; features = 0
## Hyperparameters: use.box.cox=TRUE,use.trend=TRUE,seasonal.periods=TRUE,max.p=60,max.q=60,stationary=FALSE,h=35,predict.type=response

predict.tbats = predict(train.tbats, newdata = m4.test)
```

To measure the performance of TBATS we call `performance()` with the Mean Absolute Scaled Error (MASE) [23] measure.

```
performance(predict.tbats, mase, task = climate.task)

##           mase
## 0.0676601
```

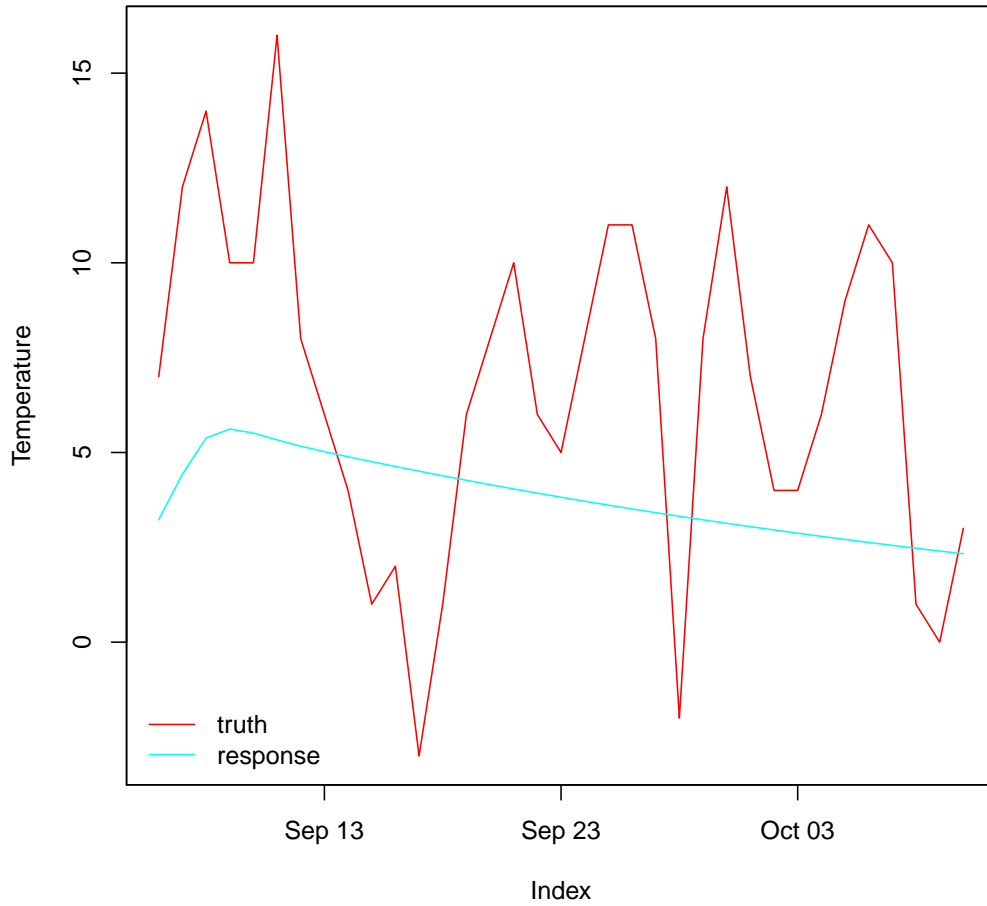
MASE has favorable properties for calculating forecast errors relative to measures such as root mean squared error or median relative absolute error. Arguably one of the most important features, it's very interpretable. Let y_t and \tilde{y}_t be the target variable and prediction at time t until the final time T with $\epsilon_t = y_t - \tilde{y}_t$ being the forecast error.

$$\text{MASE} = \frac{\sum_{t=1}^T |\epsilon_t|}{\frac{T}{T-1} \sum_{t=2}^T |y_{t,\text{insample}} - y_{t-1,\text{insample}}|} \quad (1)$$

Where the denominator is the one step ahead naive forecast from the training data. When the numerator is equal to the denominator the model performed as good as a simple naive forecast method. Scores greater than one mean you are performing worse and scores less than one mean you are performing better than the naive forecasting method.

The scale invariance of MASE means that it is independent of the scale of the data which allows models to be compared across data sets. The scale invariance of MASE has made it a favorite for comparing the accuracy of forecast methods [11] across datasets. While scaling in measures such as the Mean Absolute Percentage Error can cause poor behavior as the target variable goes to zero, MASE does not become skewed when the target variable approaches zero. This allows MASE to be use in situations in which zeros occur frequently or zero is not meaningful such as predicting temperature.

Forecast of Temperature



Need to talk about results

Because the forecasts are only for the next 35 periods it's useful to be able to update the model continuously without retraining the model each time we want new forecasts. Univariate forecasting models in **mlr** can be updated using `updateModel()`.

```
update.tbats = updateModel(train.tbats, climate.task, newdata = m4.test)
update.tbats

## Model for learner.id=fcregr.tbats; learner.class=fcregr.tbats
## Trained on: task.id = M4 Climate Data; obs = 35; features = 0
## Hyperparameters: use.box.cox=TRUE,use.trend=TRUE,seasonal.periods=TRUE,max.p=60,max.q=60,stat.i

predict(update.tbats, task = climate.task)

## Prediction: 35 observations
## predict.type: response
## threshold:
## time: 0.00
##               response
## 2009-09-04 23:59:54 6.319959
## 2009-09-05 23:59:48 7.875401
## 2009-09-06 23:59:43 8.209328
## 2009-09-07 23:59:37 8.157638
## 2009-09-08 23:59:31 8.083591
## 2009-09-09 23:59:26 8.055280
## ... (35 rows, 1 cols)
```

5.2 Multivariate Forecasting

The package **BigVAR** has been implemented for multivariate forecasting. **BigVAR** allows for estimation of high dimensional time series through including structured Lasso penalties to the vector autoregression framework [29].

```
bigvar.mod = makeLearner("mfcvreg.BigVAR",p = 25, struct = "SparseLag",
                        gran = c(50, 60),h = 35, n.ahead = 35)
```

```
train.bigvar = train(learner = bigvar.mod, task = mfcvreg.all.task )
train.bigvar
```

```
## Model for learner.id=mfcvreg.BigVAR; learner.class=mfcvreg.BigVAR
## Trained on: task.id = bigvar; obs = 1828; features = 0
## Hyperparameters: p=25,struct=SparseLag,gran=50,60,h=35,n.ahead=35
```

Predictions for `multiForecast` methods have a similar output to `multiclass` methods, returning multiple truth and response variables. A multivariate version of MASE has been implemented which takes the mean of each MASE score for the individual variables.


```

predict.bigvar = predict(train.bigvar, newdata = eu.test)
predict.bigvar

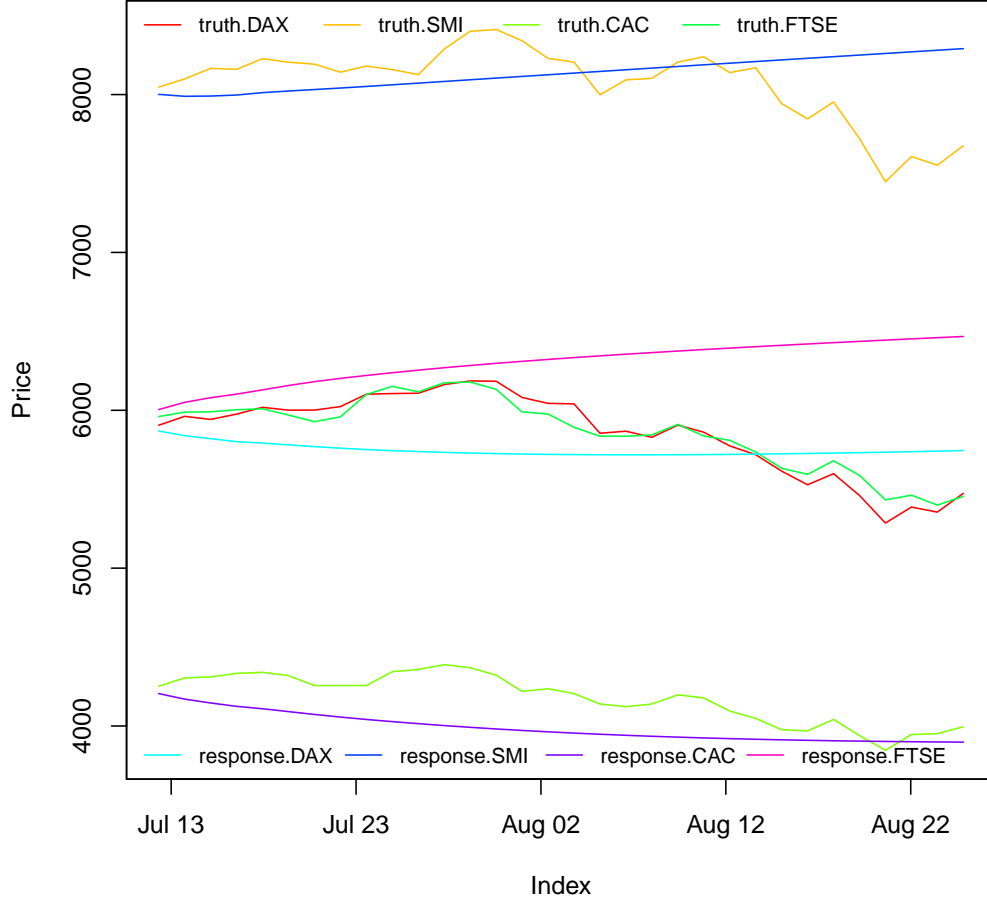
## Prediction: 32 observations
## predict.type: response
## threshold:
## time: 0.03
##
##          truth.DAX truth.SMI truth.CAC truth.FTSE response.DAX
## 1998-07-12 07:50:46   5905.15   8047.3   4252.1    5960.2   5852.841
## 1998-07-13 17:32:18   5961.45   8099.0   4304.4    5988.4   5820.194
## 1998-07-15 03:13:50   5942.06   8166.0   4311.1    5990.3   5801.712
## 1998-07-16 12:55:23   5975.88   8160.0   4333.1    6003.4   5790.565
## 1998-07-17 22:36:55   6018.89   8227.2   4339.9    6009.6   5781.540
## 1998-07-19 08:18:27   6000.84   8205.0   4319.2    5969.7   5772.087
##
##          response.SMI response.CAC response.FTSE
## 1998-07-12 07:50:46   7982.503    4192.149    5997.825
## 1998-07-13 17:32:18   7960.779    4153.550    6037.958
## 1998-07-15 03:13:50   7955.264    4130.674    6063.687
## 1998-07-16 12:55:23   7958.119    4115.612    6083.094
## 1998-07-17 22:36:55   7965.061    4103.302    6100.075
## 1998-07-19 08:18:27   7973.586    4091.154    6116.419
## ... (32 rows, 8 cols)

performance(predict.bigvar, multivar.mase, task = mfcregr.all.task)

## multivar.mase
##      0.2209703

```

Forecast of Prices for Euro Stock Indices



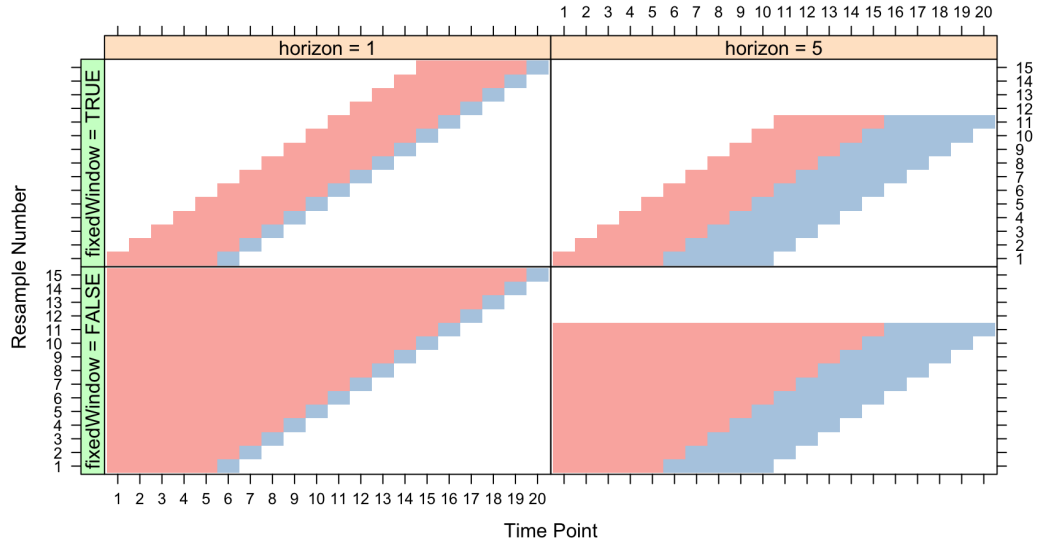
6 Resampling with Time

While TBATS is one of the most well known time series models, the order selection process or the ARIMA errors and whether to include trend, damped trend, or seasonal periods can be a subjective process that makes finding the best model difficult for users. One of the first proposals for automated forecasting methods comes from [9] for automatic order selection of ARIMA models. Innovations are obtained by fitting high order autoregressive models to the data and then computing the likelihood of potential models through a series of standard regressions. Proprietary algorithms from software such as **Forecast Pro** [34] and **Autobox** [33] are well known and have performed to high standards in competitions such as the M3 forecasting competition [27]. One of the most well known R packages for automated forecast is **forecast** [22] which contains several methods for automated forecasting including exponential smoothing based methods and step-wise algorithms for forecasting with ARIMA

models.

Forecasting in **mlr** takes a machine learning approach, creating a parameter set for a given model and using an optimization method to search over the parameter space. To do this, we will use a windowing resampling scheme to train over the possible models. Resampling schemes such as cross-validation, bootstrapping, etc. are common in machine learning for dealing with the bias-variance tradeoff [12] [35]. When there is a time component to the data, windowing schemes are useful in allowing a valid resampling scheme while still maintaining the time properties of the series. Figure one gives an example of fixed and growing windows. Given a horizon and initial starting point the window slides forward one step each time while either shifting in the fixed case or enlarging by one in the growing case. Growing and fixed window resampling such as from [21] are now available in the `resampling()` function of **mlr**.

Figure 1: Resampling with a window scheme as exemplified by caret [24]. The top graphs are fixed window cross validation while the bottom graphs are growing window cross validation.



A windowing resampling process is created in the function `makeResampleDesc()` by supplying the resampling type, horizon, initial window, the length of the series, and an optional argument to skip over some windows for the sake of time.

```
resampDesc = makeResampleDesc("GrowingCV", horizon = 35L,
                              initial.window = .7,
                              size = nrow(getTaskData(climate.task)),
                              skip = .02)

resampDesc

## Window description:
## growing with 14 iterations:
## 448 observations in initial window and 35 horizon.
## Predict: test
## Stratification: FALSE
```

To make a parameter set to tune over **mlr** uses **ParamHelpers** [4]. There are several types of tools to help us search our parameter space including grid search, random search [3], to search our parameter space for the most optimal model.

```
parSet = makeParamSet(makeLogicalParam(id = "use.box.cox", default = FALSE,
                                       tunable = TRUE),
                      makeLogicalParam(id = "use.trend", default = FALSE,
                                       tunable = TRUE),
                      makeLogicalParam(id = "use.damped.trend",
                                       default = FALSE,
                                       tunable = TRUE),
                      makeLogicalParam(id = "seasonal.periods",
                                       default = FALSE,
                                       tunable = TRUE),
                      makeIntegerParam(id = "max.p", upper = 10, lower = 0),
                      makeIntegerParam(id = "start.p", upper = 10, lower = 1,
                                       trafo = function(x) x*2),
                      makeIntegerParam(id = "max.q", upper = 20, lower = 10),
                      makeIntegerParam(id = "start.q", upper = 5, lower = 0,
                                       trafo = function(x) x*2),
                      makeIntegerParam(id = "max.P", lower = 0, upper = 3),
                      makeIntegerParam(id = "max.Q", lower = 0, upper = 2),
                      makeDiscreteParam(id = "ic",
                                       values = c("aicc", "aic", "bic")),
                      makeDiscreteParam(id = "test",
                                       values = c("kpss", "adf", "pp")),
                      makeDiscreteParam(id = "seasonal.test",
                                       values = c("ocsb", "ch")),
                      makeLogicalParam(id = "biasadj", default = FALSE)
                      )

#Specify tune by grid estimation
ctrl = makeTuneControlIrace(maxExperiments = 500L)
```

Using `tuneParams()` the model is tuned for the task using the specified resampling scheme, parameter set, tune control, and measure. For this tuning task we use MASE [23] as a measure of performance ¹.

```
#
library("parallelMap")
parallelStartSocket(6)
configureMlr(on.learner.error = "warn")
set.seed(1234)
tbatsTune = tuneParams(makeLearner("fcregr.tbats", h = 35),
                       task = climate.task, resampling = resampDesc,
                       par.set = parSet, control = ctrl, measures = mase)
parallelStop()
tbatsTune
```

```
## Tune result:
## Op. pars: use.box.cox=TRUE; use.trend=TRUE; use.damped.trend=TRUE; seasonal.periods=FALSE; max
## mase.test.mean=0.0688
```

The best model's parameters are extracted using `setHyperPars()` and passed to `train()` to go over the full data set.

```
lrn = setHyperPars(makeLearner("fcregr.tbats", h = 35),
                  par.vals = tbatsTune$x)
m = train(lrn, climate.task)
```

To make predictions for our test set we simply pass our model, task, and test data to `predict()`

```
climate.pred = predict(m, newdata = m4.test)
performance(climate.pred, measures = mase, task = climate.task)

##      mase
## 0.06145902
```

For comparison, TBATS is run in `forecast` with it's base parameters

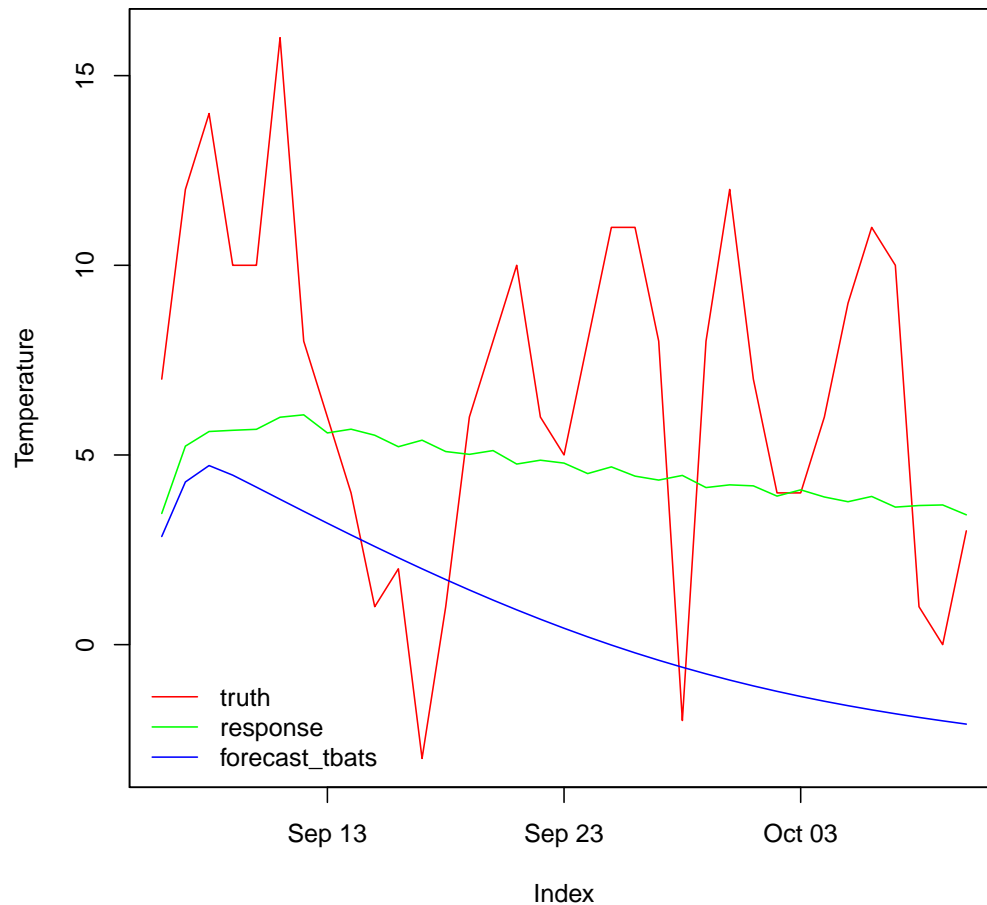
```
library(forecast)
forecast.train.tbats <- tbats(ts(m4.train,frequency = 365))
forecast.tbats <- forecast(forecast.train.tbats,h=35)
# Calculate MASE
sum(abs(coredata(m4.test)-forecast.tbats$mean)) /
  ((nrow(m4.test) / (nrow(m4.test) + 1)) *
   sum(abs(diff(coredata(m4.test))))))

## [1] 1.951852
```

¹Models with a seasonal difference > 0 may be favorably biased as we use the non-seasonal MASE score

Now it's possible to see the clear benefit of the forecast extension to **mlr**. Normal tuning of this model would require extensive manual testing in an attempt to find the best model. By automating this process we come to a faster solution with minimal work.

Tuned Forecast of Temperature



To this author's knowledge, this is the first package in R that allows for tuning and training GARCH models [10]. It is possible to pass and train multiple types of GARCH models while also tuning the models respective parameters. In this example we also use 'predict.type = "quantile"' to estimate confidence intervals for the forecast.

```
par_set = makeParamSet(
  makeDiscreteParam(id = "model", values = c("sGARCH", "csGARCH")),
  makeIntegerVectorParam(id = "garchOrder", len = 2L, lower = c(1,1),
    upper = c(4,4)),
  makeIntegerVectorParam(id = "armaOrder", len = 2L, lower = c(5,1),
    upper = c(8,3)),
```

```

makeLogicalParam(id = "include.mean"),
makeLogicalParam(id = "archm"),
makeDiscreteParam(id = "distribution.model",
                  values = c("norm","std","jsu")),
makeDiscreteParam(id = "stationarity", c(0,1)),
makeDiscreteParam(id = "fixed.se", c(0,1)),
makeDiscreteParam(id = "solver", values = "nloptr"),
makeIntegerParam(id = "n.ahead", default = 35L, lower = 35L,
                 upper = 36L, tunable = FALSE)
)

#Specify tune by grid estimation
ctrl = makeTuneControlIrace(maxExperiments = 400L)

parallelStartSocket(6)
configureMlr(on.learner.error = "warn")
set.seed(1234)
garchTune = tuneParams("fcgrg.garch", task = climate.task,
                      resampling = resampDesc, par.set = par_set,
                      control = ctrl, measures = mase)

parallelStop()
garchTune

```

```

## Tune result:
## Op. pars: model=sGARCH; garchOrder=4,1; armaOrder=7,2; include.mean=TRUE; archm=FALSE; distrib
## mase.test.mean=0.0789

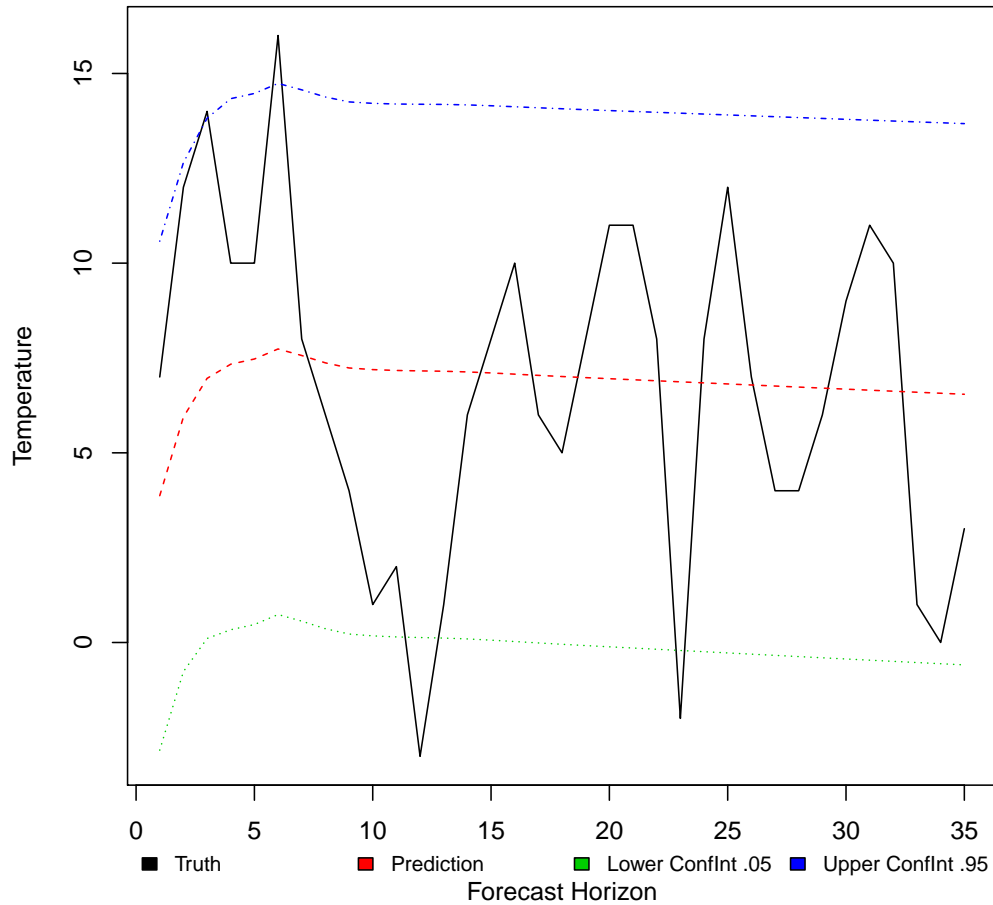
```

```

##      mase
## 0.05589035

```

Forecast of Daily Climate Data With Confidence Intervals



7 Forecasting with Machine Learning Models

7.1 Forecasting with Regression Tasks

The forecasting extension of **mlr** includes a preprocessing function that allows supervised machine learning models. the function `createLagDiffFeatures()` allows for $AR(p,d)$ structures to be imbedded in machine learning models.

```
climate.regr.task = makeRegrTask(id = "lagged gbm",
                                data = as.data.frame(m4.train),
                                target = "target_var")
climate.task.lag = createLagDiffFeatures(climate.regr.task,
                                         lag = 1L:100L, difference = 1L,
```



```

seasonal.lag = 1L:2L, na.pad=FALSE)

climate.task.lag

## Supervised task: lagged gbm
## Type: regr
## Target: target_var
## Observations: 539
## Features:
## numerics  factors  ordered
##      100      0      0
## Missings: FALSE
## Has weights: FALSE
## Has blocking: FALSE

```

Notice that `createLagDiffFeatures()` returns a new task with the lagged variables as the new features. Once the lagged task is created the model is trained or tuned like any other.

```

lag.gbm = makeLearner("regr.gbm", par.vals = list(n.trees = 100))
gbm.train = train(lag.gbm, climate.task.lag)

```

The `forecast()` function allows machine learning models to do arbitrary n-step ahead forecasts which in the package is defined as

$$\hat{y}_{t+n} = \sum_{p=t}^{n-1} \rho_p \Delta_d \hat{y}_p + \epsilon_p \quad (2)$$

Where n is the number of steps ahead to forecast, p is the autoregressive order and d is the lag of the difference operator.

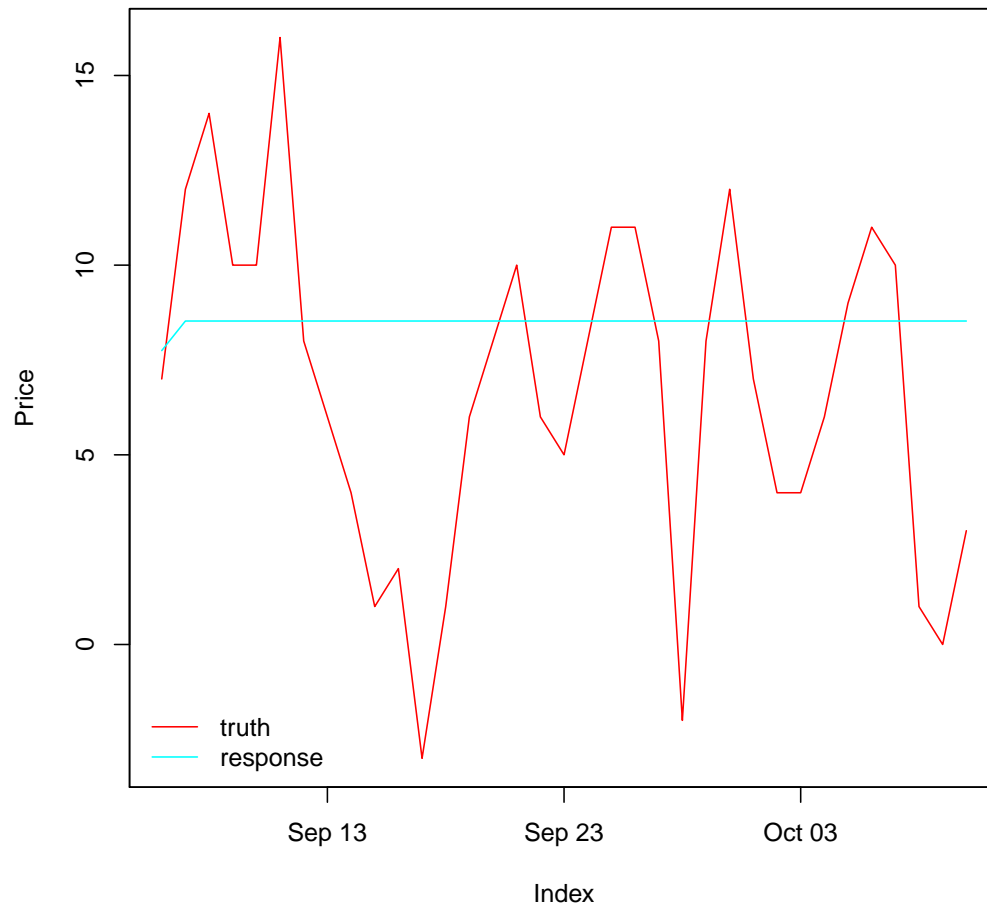
```

m4.test.df = as.data.frame(m4.test, row.names = index(m4.test))
gbm.forecast = forecast(gbm.train, h = 35L,
                        newdata = m4.test.df)
performance(gbm.forecast, mase, climate.regr.task)

##      mase
## 0.0571994

```

Tuned Forecast of Temperature



7.2 Forecasting with Classification Tasks

For developing trading strategies, we normally have a discrete set of choices such as to buy, sell, or hold onto a stock. Using forecasting in `mlr` we can now train classification models that forecast these choices [25]. To example this, a simple buy, sell, or hold trading strategy will be built Using the `EuStockMarkets`'s DAX index. If the stock goes up by 5% in a day we will buy, down 5% we will sell, and otherwise we will hold onto the current stocks we have.

```
DAX = EuStockMarkets$DAX/lag(EuStockMarkets$DAX,  
                             7,nap.pad = FALSE) - 1  
trade.strat = ifelse(DAX > .02, "Buy",  
                    ifelse(DAX < -.01, "Sell", "Hold"))  
trade.strat = trade.strat[8:1860]
```

```

euro.classif.data = data.frame(trade.strat = trade.strat ,
                              row.names = index(trade.strat))
# Note: Error on multiples of the same observation
euro.classif.train = euro.classif.data[1:1850,,drop = FALSE]
euro.classif.test  = euro.classif.data[1851:1853,,drop = FALSE]
classif.task = makeClassifTask(data = euro.classif.train,
                              target = "DAX")
classif.task.lag = createLagDiffFeatures(classif.task,
                                       lag = 1L:365L,
                                       na.pad = FALSE)
classif.learn = makeLearner("classif.boosting", xval = 1,
                           mfina1 = 200, minsplit = 10)

classif.train = train(classif.learn, classif.task.lag)
classif.fc = forecast(classif.train, h=2, newdata = euro.classif.test)
performance(classif.fc)

## Prediction: 32 observations
## predict.type: response
## threshold:
## time: 125.91
##   truth response
## 1   Buy      Buy
## 2   Buy      Buy
## 3   Hold     Buy
## 4   Hold     Buy
## 5   Hold     Buy
## 6   Buy      Buy
## ... (32 rows, 2 cols)
##   mmce
## 0.6875

```

8 Lambert W Transforms

Many machine learning and time series models rely on the assumption that our data or errors fit a normal distribution. This assumption becomes precarious when modeling the asymmetric and fat-tailed data of the real world. Lambert W Transforms are a family of generalized skewed distributions [15] that have bijective and parametric functions that allow heavy tailed and asymmetric data to appear more Gaussian [16].

Let U be a continuous random variable with cdf $F_U(u|\beta)$ and pdf $f_U(u|\beta)$ given β is a parameter vector. Define a continuous location-scale random variable $X \sim F_X(x|\beta)$. A location-scale skewed Lambert $W \times F_X$ random variable is defined as

$$test \tag{3}$$

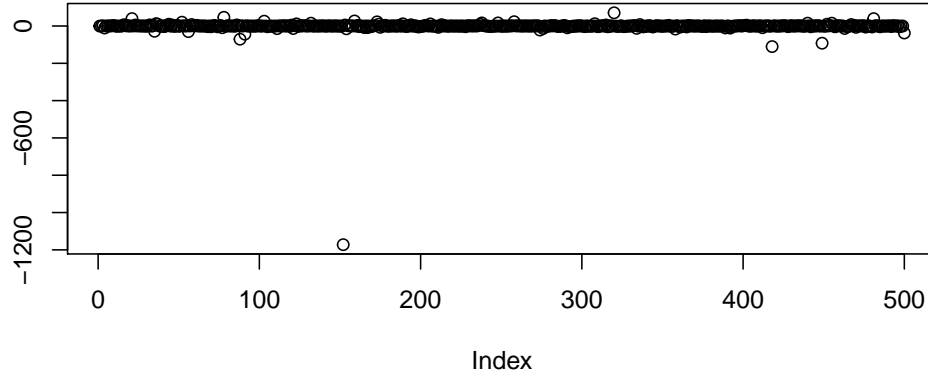
And the heavy-tailed Lambert $W \times F_X$ random variable can be defined as

$$test \tag{4}$$

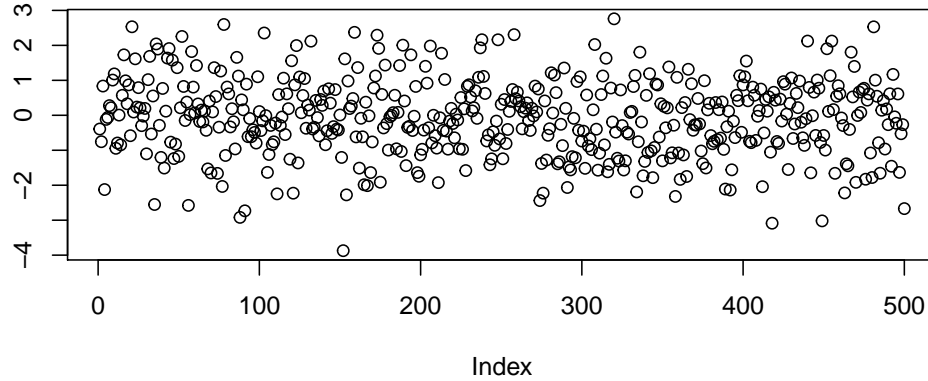
Given that $U = (X - \mu_X)/\sigma_X$ where μ_X , σ_X , δ , and α are the mean and standard deviation of X and the parameters to control skewness and asymmetry, respectively. When $\delta = 0$, equation 12 reduces to a standard normal distribution. Equation 12 is the general form of Tukey's h distribution [20] and the basis for Morgenthaler and Tukey's [28] skewed, heavy tailed family of hh random variables.

$$Z = \begin{cases} U \exp\left(\frac{\delta_l}{2}(U^2)_l^\alpha\right), & \delta_l \geq 0, \alpha_l > 0 \\ U \exp\left(\frac{\delta_r}{2}(U^2)_r^\alpha\right), & \delta_r \geq 0, \alpha_r > 0 \end{cases} \tag{5}$$

Cauchy Samples



Cauchy Samples With Lambert 'h' Transform



The function **Gaussianize** is available in the package **LambertW** and has been made into a preprocessing function in **mlr**.

```

# Need to make this more dramatic
lamb.lrn = makePreprocWrapperLambert("classif.lda", type = "h")
lamb.lrn

## Learner classif.lda.preproc from package MASS
## Type: classif
## Name: ; Short name:
## Class: PreprocWrapperLambert
## Properties: numerics,factors,prob,twoclass,multiclass
## Predict-Type: response
## Hyperparameters: type=h,methods=IGMM,verbose=FALSE

lamb.trn = train(lamb.lrn,iris.task, subset = 1:120)
lamb.pred = predict(lamb.trn, iris.task, subset = 121:150)

# Do the non-LW version
trn = train(makeLearner("classif.lda"),iris.task, subset = 1:120)
pred = predict(trn, iris.task, subset = 121:150)
performance(lamb.pred)

## mmce
## 0.1

performance(pred)

## mmce
## 0.1

```

9 Stacking Forecasting Learners

Stacking is a form of ensemble learning [8] in which a learning algorithm is trained on the predictions of several other learning algorithms. Let $y_{i,m}$ be the prediction at time i of model m . Given an aggregation function ϕ , a stacked forecast learner [7] is represented as

$$\tilde{y}_{i+1} = \phi(\tilde{y}_{i+1,1}, \tilde{y}_{i+1,2}, \dots, \tilde{y}_{i+1,m}, \sum_{j=1}^m \epsilon_{i+1,j}) \quad (6)$$

For a simple ϕ such as the ensemble average then equation 6 becomes

$$\tilde{y}_{i+1} = \frac{\tilde{y}_{i+1,1} + \tilde{y}_{i+1,2} + \dots + \tilde{y}_{i+1,m}}{m} \quad (7)$$

In section 9.1 the simple model average is used to show how stacked forecast models are built in **mlr**. Section 9.2 does a more advanced method of ensemble averaging involving the forecast of endogeneous variables.

9.1 Stacking Univariate Learners

For this example the models TBATS, GARCH, and ARFIMA [18] are stacked together and averaged on the climate task data. A resample description is made, and the function `makeLearners()` is used to start multiple learners at the same time.

```
resamp.sub = makeResampleDesc("GrowingCV",
                              horizon = 35L,
                              initial.window = .90,
                              size = nrow(getTaskData(climate.task)),
                              skip = .01
                              )

lrns = makeLearners(c("fcregr.tbats", "fcregr.garch", "fcregr.arfima"))
```

The function `makeStackedLearner()` takes the initialized learners and sets the meta information for stacking. This method uses simple model averaging such as ϕ , however a super learner [37] can be used here, where $\phi()$ becomes another machine learning model.

```
stack.forecast = makeStackedLearner(base.learners = lrns,
                                   predict.type = "response",
                                   method = "average")
```

Each of the stacked learners are tuned over the cross product of all model parameters. This leads to a change in design where, given that some models may have the same argument names, the full name of the model is placed before the argument. This leads to longer code, but tuning over the cross product of the models allows for a more honest perspective of how each model interacts in the stack.

```
# Simple param set for tuning sub learners
ps = makeParamSet(
  makeDiscreteParam("fcregr.tbats.h", values = 35),
  makeDiscreteParam("fcregr.garch.n.ahead", values = 35),
  makeDiscreteParam("fcregr.arfima.h", values = 35),
  makeDiscreteParam("fcregr.arfima.estim", values = "ls"),
  makeDiscreteParam(id = "fcregr.garch.model", values = c("csGARCH")),
  makeIntegerVectorParam(id = "fcregr.garch.garchOrder",
                        len = 2L, lower = c(1),
                        upper = c(3)),
  makeIntegerVectorParam(id = "fcregr.garch.armaOrder",
                        len = 2L, lower = c(1),
                        upper = c(3)),
  makeDiscreteParam("fcregr.tbats.test", values = c("kpss", "adf", "pp"))
)

## tuning
library(parallelMap)
parallelStartSocket(4)
```

```

configureMlr(on.learner.error = "warn")
set.seed(1234)
fore.tune = tuneParams(stack.forecast, climate.task, resampling = resamp.sub,
                      par.set = ps, control = makeTuneControlGrid(),
                      measures = mase, show.info = FALSE)
parallelStop()
fore.tune

```

The rest of the modeling process flows in a way similar to normal models. the function `setHyperPars2()` takes the best parameter models from the tuning process and assigns it to the final model to train over all of the data. Training and prediction are handled in the same manner as univariate forecasters.

```

# get hyper params
stack.forecast.tune = setHyperPars2(stack.forecast,fore.tune$x)
stack.forecast.tune

# Train the final best models and predict
stack.forecast.mod = train(stack.forecast.tune,fcregr.task)
stack.forecast.pred = predict(stack.forecast.mod, newdata = dat.test)
stack.forecast.pred

```

9.2 Multivariate Stacked Learner

```

multfore.task = makeMultiForecastRegrTask(id = "bigvar", data = eu.train, target = "FTSE")

resamp.sub = makeResampleDesc("GrowingCV",
                             horizon = 32L,
                             initial.window = .90,
                             size = nrow(getTaskData(multfore.task)),
                             skip = .01
)

resamp.super = makeResampleDesc("CV", iters = 3)

base = c("mfcregr.BigVAR")
lrns = lapply(base, makeLearner)
lrns = lapply(lrns, setPredictType, "response")
lrns[[1]]$par.vals$verbose = FALSE

stack.forecast = makeStackedLearner(base.learners = lrns,
                                    predict.type = "response",
                                    super.learner = makeLearner("regr.earth", penalty = 2),
                                    method = "growing.cv",
                                    resampling = resamp.sub)

```

```

ps = makeParamSet(
  makeDiscreteParam("mfcregr.BigVAR.p", values = 5),
  makeDiscreteParam("mfcregr.BigVAR.struct", values = "Basic"),
  makeNumericVectorParam("mfcregr.BigVAR.gran", len = 2L, lower = 25, upper = 30),
  makeDiscreteParam("mfcregr.BigVAR.h", values = 32),
  makeDiscreteParam("mfcregr.BigVAR.n.ahead", values = 32)
)

## tuning
library(parallelMap)
parallelStartSocket(4)
configureMlr(on.learner.error = "warn")
set.seed(1234)
multfore.tune = tuneParams(stack.forecast, multfore.task, resampling = resamp.sub,
  par.set = ps, control = makeTuneControlGrid(),
  measures = multivar.mase, show.info = FALSE)

parallelStop()
multfore.tune

stack.forecast.f = setHyperPars2(stack.forecast, multfore.tune$x)
multfore.train = train(stack.forecast.f, multfore.task)
multfore.train

multfore.pred = predict(multfore.train, newdata = as.data.frame(eu.test))
multfore.pred

performance(multfore.pred, mase, task = multfore.task)

```


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