boxfilter: Filter Heart Rates

Thomas Ruf

Veterinary University Vienna, Austria

Heart rates and other signals recorded in humans and animals often contain noise. This can be removed by hand or various filters. Filters may be based on signal characteristics or on limiting the signal to certain frequencies. An alternative is boxfilter. The filter was designed to assign each data point a weight based on the number of neighboring points. This principle is based on genuine points surrounding the focal point, whether the data are normally distributed or show positive autocorrelation.This was implemented by looping through all data points and counting neighbors within a rectangular frame, adjustable in width and height and centered on a focal data point. It weighs all data points in a given data set according to the proportion of neighbors and retains only those points with high proportions.

The data, which may be stored in a comma separated file (.csv) consist of a time (x) a heartrate (y) and possibly a quality index (QI). They can be read like this (assuming HRS.csv is in the present directory):

```
dat=read.csv ("HRS.csv")
head(dat) # shows the first lines
```

boxfilter prefers points within a dense band and rejects isolated values. The filter result depends on both window size and the choice of the clip-off value beyond which data points are discarded. We recommend to keep the window size (width and height) fixed while varying clipit, the cutoff value. by default, th window is quadratic. All three parameters can be computed automatically. For this purpose use like this:

```
library(boxfilter)
x=dat$x
y=dat$hr
QT=dat$QT
boxclip(x,y,QI)
```

Here, the shades of blue in the upper graph indicate signal quality, as provided by the logger's manufacturer. These is not needed by boxclip() and is in fact ignored in computations. The quality is merely shown in the graph of original points to illustrate that high values of the heart rate, as they occur in summer, are very unreliable. Not surprisingly then, in filtered points, with filtering based on their density, there is even a drop in heart rates in summer and a peak in winter, in wild boar[1]. This is shown in the filtered signal in the lower graph (red points). The value for clipit (here 0.45) was automatically computed, since it was omitted. In this case, boxclip() even discards points that were considered "good quality" (QI 0-1; dark blue) by the manufacturer. The default window height is half of th heat rate mean. The default width is half of the height, which is only half of th window height.

It may seem that the boxfilter is only suited to remove white noise surrounding the data. This is not the case. Sometimes the genuine signal may contain "bands" of noise. For example, a heart rate logger based on the acoustics of the heart beat in ruminants [2], occasionally picks up noise corresponding to
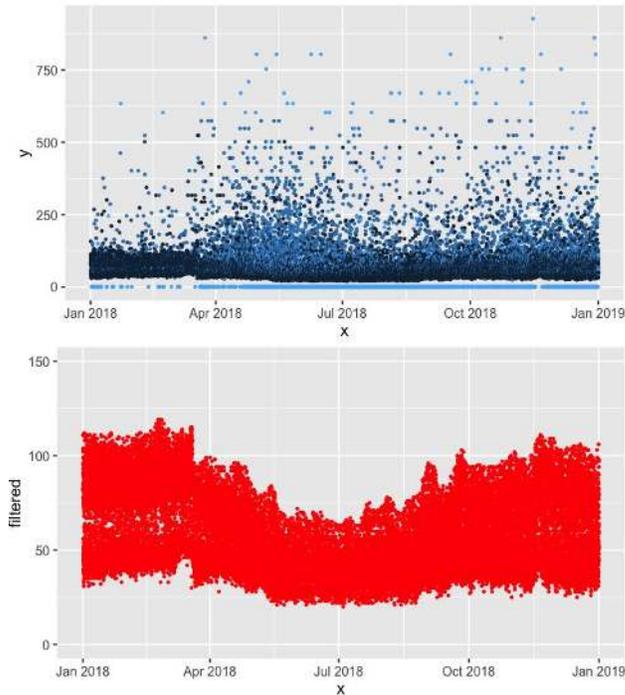
Figure 1: Yearly heartrate of a wild boar.Upper graph: original points; lower graph: filtered points.

approximately 110 bpm. An example of year-round record in a Capricorn is shown in the next figure. It was generated with:

```
boxclip(x,y,clipit=0.65)
```

The false bands are removed because they are not surrounded by a genuine signal. Obviously, boxfilter is mainly suited to identify the major tendency in a data set. The automatic computation of clipit is merely a suggestion that may be far away from a sensible value. It may be found by try and error. To this end, the function clipview() may be helpful. It gives the result of using a sequence of four different clipit values (shown in the upper left corner of each result).

```
clipview (x,y,clipit=seq(0.05, 0.2 ,by=0.05))
```

A clipit value of 0 leaves the data unchanged. Larger values of clipit remove more original points. Use e.g. clipit=c(0.1,0.3,0.5,0.7) for regular increments. The figure also shows a histogram of the proportion of neighbors surrounding a point. The histogram may be helpful in determining clipit. In the automatic calculation the value of clipit corresponds to the first drop >0 in the histogram. Of course, boxfilter may be applied also to other measures than heart rate that do not change instantaneously, such as temperature or blood pressure. For an example on the time spent is bed during a sleep-study (https://www.kaggle.com/datasets/danagerous/sleep-data) see last example of boxclip.
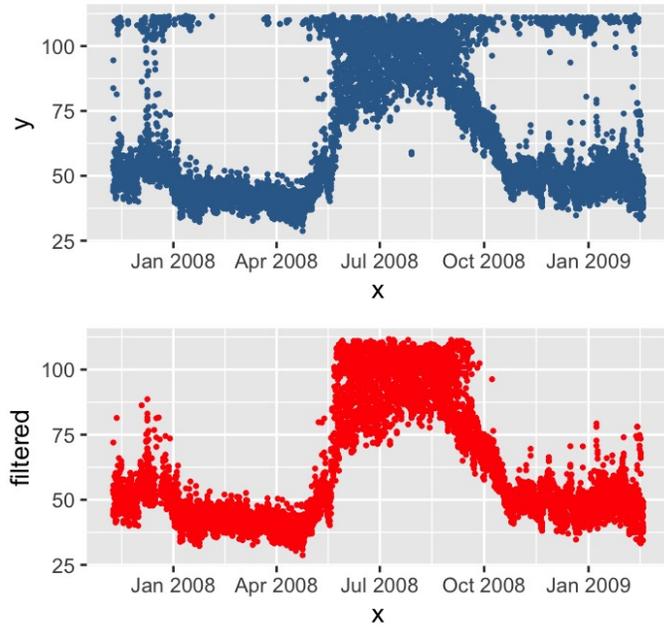
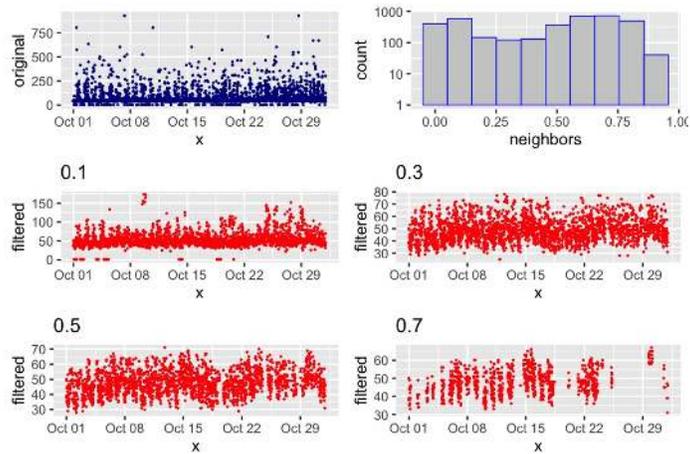Figure 2: Yearly heartrate of an ibex.Upper graph: original points; lower graph: filtered points.

Figure 3: Result of trying clipview with four values of clipit ranging from 0.1 to 0.7.

To store the results of boxclip() use:

```
bc=boxclip (x,y)
data=data.frame(x=bc$x, hrf=bc$filtered)
data=na.omit(data)
write.csv(data,file="myheartrates.csv")
```

References:
Signer, C., Ruf, T., Schober, F., Fluch, G., Paumann, T., & Arnold, W. (2010). A versatile telemetry system for continuous measurement of heart rate, body temperature and locomotor activity in free-ranging ruminants. Methods in Ecology and Evolution, 1(1), 75-85.
Ruf, T., Vetter, S. G., Painer, J., Stalder, G., & Bieber, C. (2021). Atypical for northern ungulates, energy metabolism is lowest during summer in female wild boars (Sus scrofa). Scientific Reports, 11(1), 1-12.