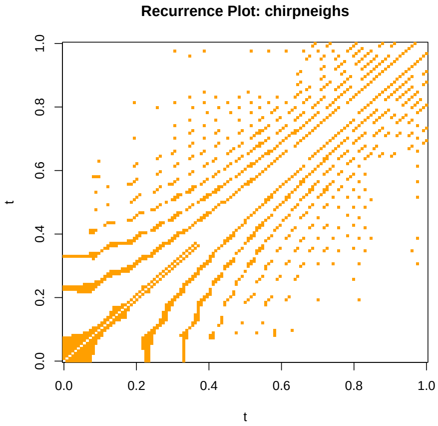
STATISTICAL DATA ANALYSIS: RECURRENCE PLOT

GÜNTHER SAWITZKI



Contents

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Key words and phrases. data analysis, distribution diagnostics, recurrence plot.
This waste book is a companion to "G. Sawitzki: Statistical Data Analysis"
Typeset, with minor revisions: February 10, 2014 from cvs *Revision* : 1.2
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1. Setup

Input
```
save.RNGseed <- 87149 #.Random.seed
save.RNGkind <- RNGkind()
# save.RNGseed
save.RNGkind
```

Output
```
[1] "Mersenne-Twister" "Inversion"
```

Input
```
set.seed(save.RNGseed, save.RNGkind[1])
```

Input
```
laptime <- function(){
return(round(structure(proc.time() - chunk.time.start, class = "proc_time")[3],3))
chunk.time.start <<- proc.time()
}
```

Input
```
# install.packages("sintro",repos="http://r-forge.r-project.org",type="source")
library(sintro)
```

We use

Input
```
library(nonlinearTseries)
```

To display state space, we us a variant of pairs().

Input
```
statepairs <- function(states, rank=FALSE){
        main <- paste("Takens states:",deparse(substitute(states)))
        if (rank) {states <- apply(uniftakens,2,rank,ties.method="random")
        main <- paste(main," ranked")}
        pairs(states,
        main=main,
        col=rgb(0,0,0,0.2))
}
```

1.1. **Local Bottleneck.** To allow experimental implementations, functions from nonlinearTseries are aliased here.

Input
```
local.buildTakens <- buildTakens
```

Input
```
local.findAllNeighbours <- nonlinearTseries:::findAllNeighbours
```

minor cosmetics added to recurrencePlotAux

Input

```
#non-sparse variant
#local.recurrencePlotAux <- nonlinearTseries:::recurrencePlotAux
local.recurrencePlotAux=function(neighs){
        neighbourListNeighbourMatrix  = function(){
          #neighs.matrix = Diagonal(ntakens)
          for (i in 1:ntakens){
            if (length(neighs[[i]])>0){
              for (j in neighs[[i]]){
                neighs.matrix[i,j] = 1
              }
            }
          }
         # return (neighs.matrix)
        }

  ntakens=length(neighs)
  neighs.matrix <- matrix(nrow=ntakens,ncol=ntakens)
  #neighbourListNeighbourMatrix()
    #neighs.matrix = Diagonal(ntakens)
          for (i in 1:ntakens){
            if (length(neighs[[i]])>0){
              for (j in neighs[[i]]){
                neighs.matrix[i,j] = 1
              }
            }
          }

  # need no print because it is not a trellis object!!
  #print(
          image(neighs.matrix,xlab="t", ylab="t",
                main=paste("Recurrence Plot:",
                        deparse(substitute(neighs))
                        )
               )
 #        )
}
```

2. Test Cases

We set up a small series of test signals.

For convenience, some source code from other libraries is included to make this self-contained.

As a global constant, we set up the length of the series to be used.

Input

```
nsignal <- 128
system.time.start <- proc.time()
```

For representation, we use a common layout.

Input

```
plotsignal <- function (signal) {
par(mfrow=c(1,2))
plot(signal, col="blue", pch=20, xlab="t" )

plot(signal, type="l",
        main=deparse(substitute(signal)), xlab="t")
points(signal, col="blue", pch=20 )
}
```

Input
```
sin10 <- function(n=nsignal) {sin( (1:n)/n* 2*pi*10)}
plotsignal(sin10())
```

See Figure 1,

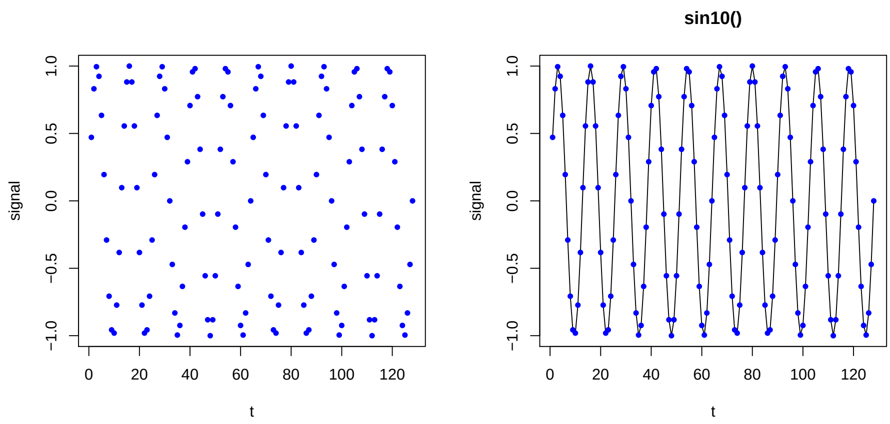

FIGURE 1. Test case: sin10. Signal and linear interpolation.

Input
```
unif <- function(n=nsignal) {runif(n)}
xunif<-unif()
plotsignal(xunif)
```

See Figure 2 on the next page,

Input
```
chirp <- function(n=nsignal) {
# this is copied from library(signal)
signal.chirp <- function(t, f0 = 0, t1 = 1, f1 = 100,
                  form = c("linear", "quadratic", "logarithmic"), phase = 0){

  form <- match.arg(form)
  phase <- 2*pi*phase/360

  switch(form,
    "linear" = {
        a <- pi*(f1 - f0)/t1
        b <- 2*pi*f0
        cos(a*t^2 + b*t + phase)
```

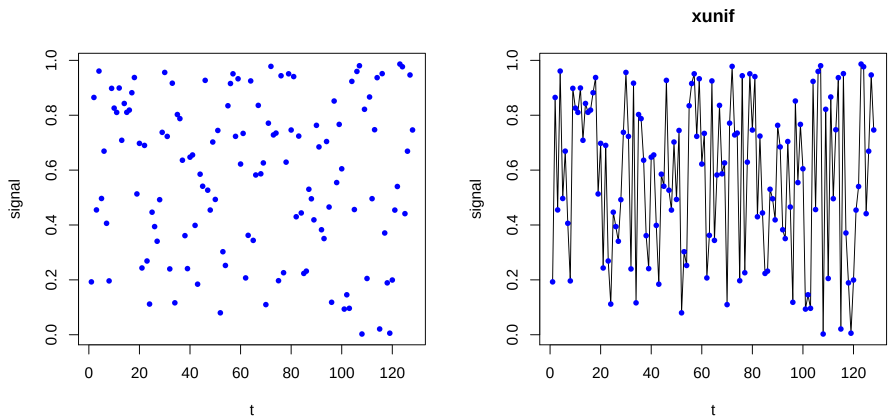

FIGURE 2. Test case: unif - uniform random numbers. Signal and linear interpolation.

```
    },
    "quadratic" = {
        a <- (2/3*pi*(f1-f0)/t1/t1)
        b <- 2*pi*f0
        cos(a*t^3 + b*t + phase)
    },
    "logarithmic" = {
        a <- 2*pi * t1 / log(f1 - f0)
        b <- 2*pi * f0
        x <- (f1-f0)^(1/t1)
        cos(a*x^t + b*t + phase)
    })
}

signal.chirp(seq(0, 0.6, len=nsignal))
}
plotsignal(chirp())
```

See Figure 3,

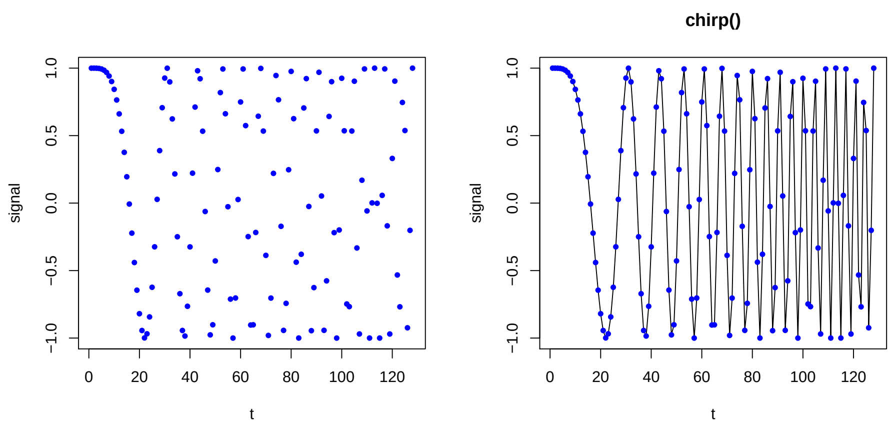

FIGURE 3. Test case: chirp signal. Signal and linear interpolation.

ToDo:
doppler wav

3. Takens' Recurrence States

Recurrence plots have been introduced in an attempt to understand near periodic in hydrodynamics. On the one hand, and etended theory on dynamical systems was available, covering deterministic models. A fundamental concept is that at a certain time a system is in some state, and developing from this. Defining the proper state space is a critical step in modelling.

The other toolkit ist that of stochastics processes, in particular Markov models. Classical time series assumes stationarity, and this is obviously not the way to go. A fundamental idea for Markov models is that the system state is seen in a temporal context: you have a Markov process, if you can define a (non-anticpating) state that has sufficient information for prediction: given this state, the future is independent from the past.

Recurrence, coming back to some state, is often a key to understand a near periodic system.

Hydrodynamics is a challenging problem. Understanding planetary motion is a historical challenge, and may be useful as an illustration.

As a simple illustration, let $x = (x_i)$ be a sequence, maybe near periodic. For now, think of i as a time index.

Recurrency plots have two steps. The first was a bold step by Floris Takens. If you do not know the state space of a system, for a choice of "dimension" d, take the sequence of d tuples taken from your data to define the states.

$$u_i = (x_i, \ldots, x_{i+d})$$

As a mere technical refinement: you may know that your data are a flattenened representation of t dimensional data. So you take

$$u_i = (x_i, \ldots, x_{i+d*m}).$$

This may be a relict of FORTRAN times, where it was common to flatten two-dimensional strctures by case. We ignore this detail here and take $m = 1$.

ToDo: add support for higher dimensional signals

Conceptually, you define states by observed histories. For classical Markov setup, the state is defined by the previous information x_{i-1}, but for more comles situations you may have to step back in the past. Finding the appropriate d is the challenge. So it may be appropriate to view the Takens staes as a family, indexed by the time scope d. The rest is structural information how to arrange items.

Of course it is possible to compress information here, sorting states and removing duplicates. Keeping the original definition as the advantage that we have the index i, so that u_i is the state at index position i.

But the states may have an inherent structure, which we may take into account or ignore. Since for this example, we are just in 4-dimensional space, marginal scatterplots may give enough information.

Input
```
sintakens <- local.buildTakens( time.series=sin10(),embedding.dim=4, time.lag=1)
statepairs(sintakens)
```

See Figure 4 on the next page.

Input
```
uniftakens <- local.buildTakens( time.series=xunif,embedding.dim=4,time.lag=1)
statepairs(uniftakens)
```

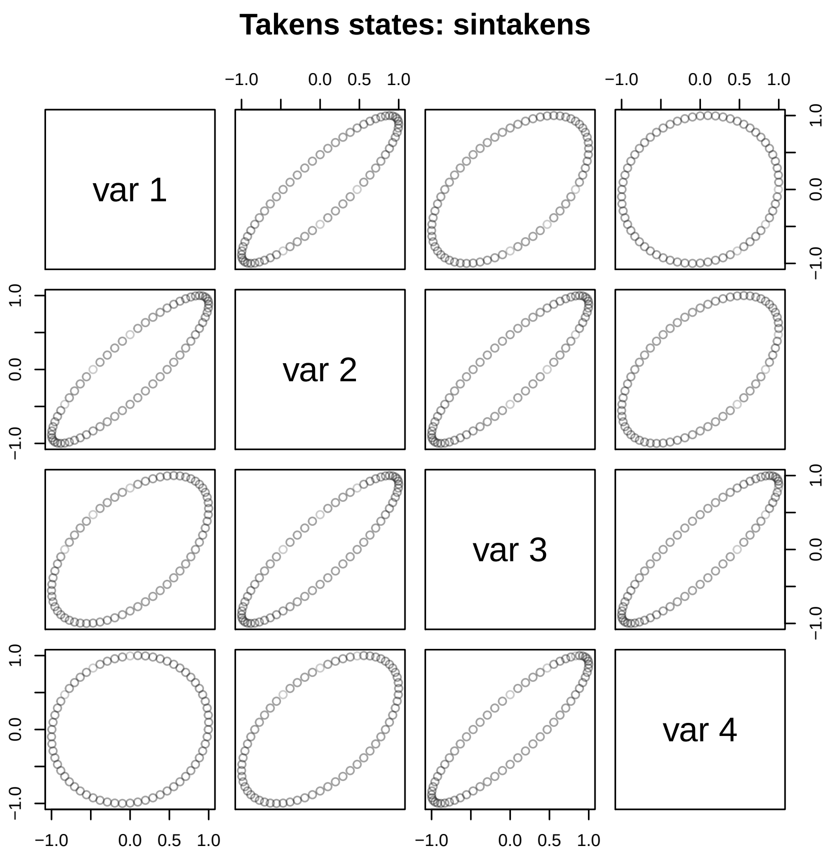

FIGURE 4. Test case: sinus. Note that marginal views of 1-dimensional circles in d space may appear as ellipses. Time used: 0.201 sec.

See Figure 5 on the following page.

Input
```
chirptakens <- local.buildTakens( time.series=chirp(),embedding.dim=4,time.lag=1)
statepairs(chirptakens)
```

See Figure 6 on page 9

4. Recurrence Plots

The next step, taken in Eckmann *et al.* [1987] was to use a two dimensional display. Take a scatterplot with the Taken's staes a marginal. Take a sliding window of your process data, and for each i, find the "distance" of u_i from and to any of the collected states. If the distance is below some chosen threshold, mark the point (i, j) for which u(j) is in the ball of radius r(i) centred at u(i).

The original publication Eckmann *et al.* [1987] actually used a nearest neighbourhood evnironment to cover about 10 data points.

The construction has considerable arbitrary choices. The critical radius may depend on the point i. In practical applications, using a constant radius is a common first step. Using a dichotomous

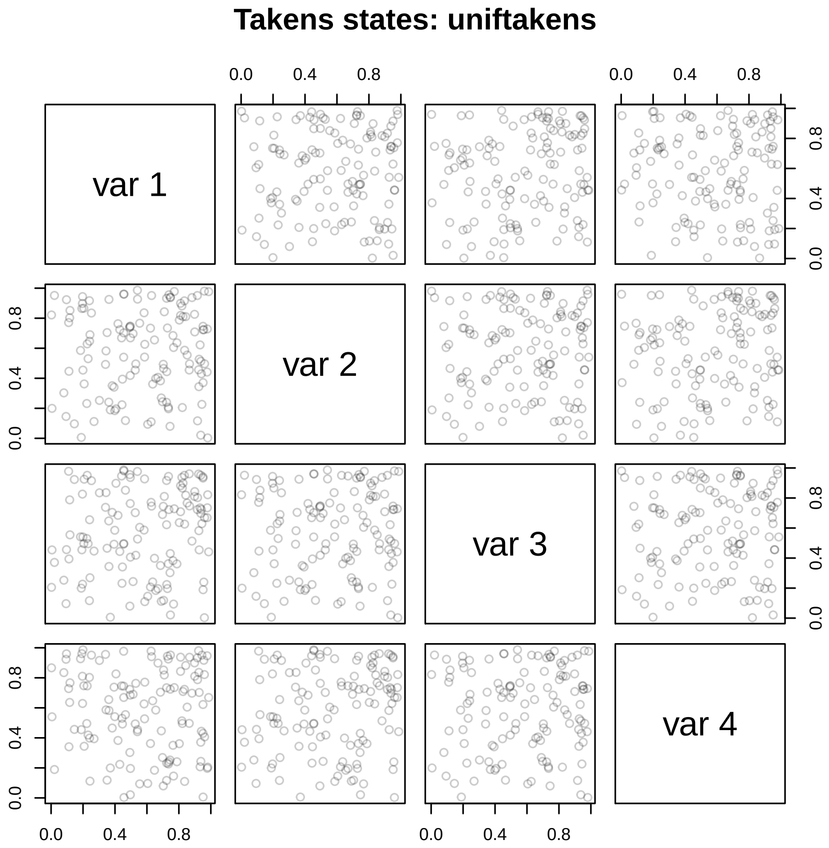

FIGURE 5. Test case: uniform random numbers. Time used: 0.212 sec.

marking was what presumably was necessary when the idea was introduced. With todays technology, we can allow a markup on a finer scale, as has been seen in Orion-1.

ToDo: support distance instead of 0/1 indicators

We can gain additional freedom by using a correlation view: instead of looking from one axis, we can walk along the diagonal, using two reference axis.

Helpful hints how to interpret recurrence plots are in "Recurrence Plots At A Glance" `<http://www.recurrence-plot.tk/glance.php>`.

4.1. Sinus.

Input

```
load(file="sin10neighs.RData")
local.recurrencePlotAux(sin10neighs)
```

4.2. Uniform random.

Input

```
load(file="unifneighs.RData")
local.recurrencePlotAux(unifneighs)
```

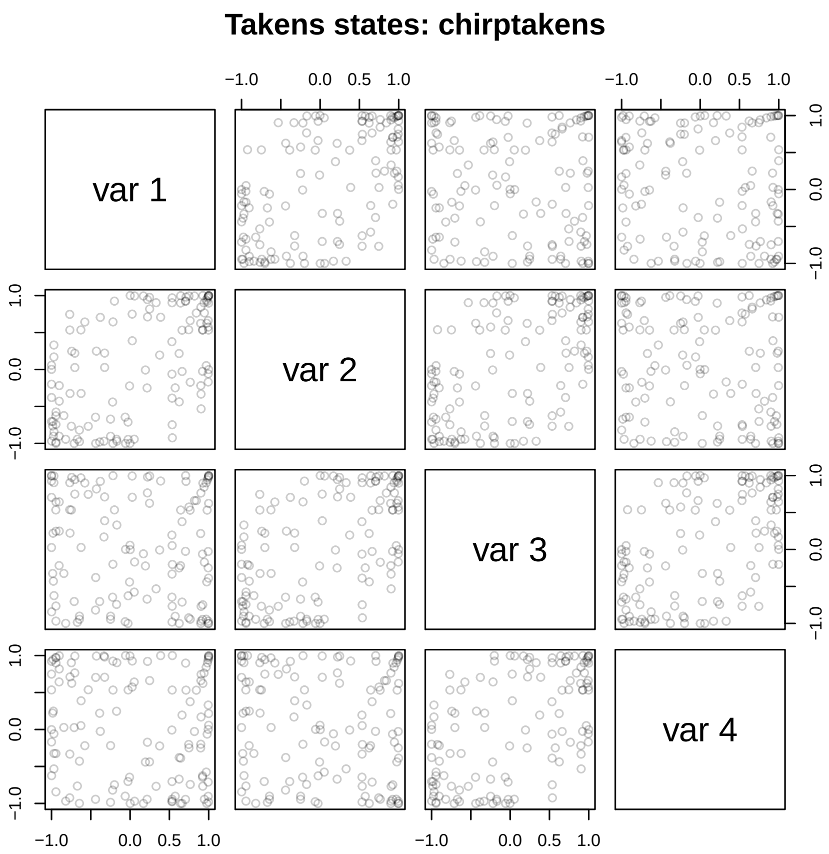

FIGURE 6. Test case: chirp signal. Time used: 0.192 sec.

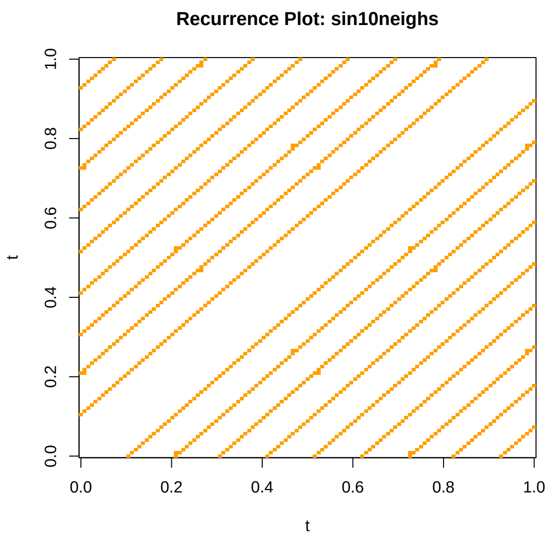

FIGURE 7. Recurrence Plot. Test case: sinus curves. Time used: 0.091 sec.

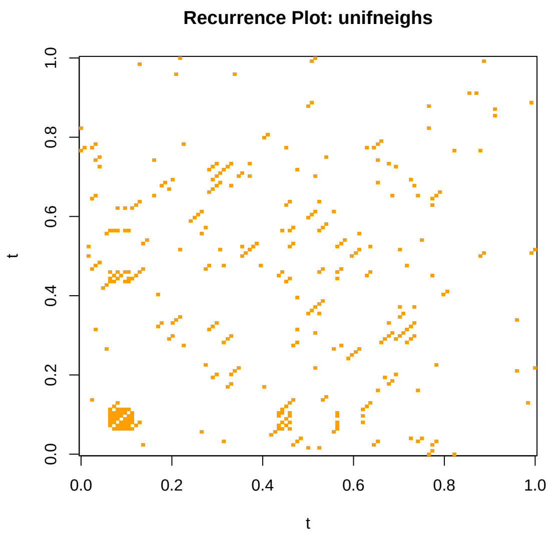

FIGURE 8. Recurrence Plot. Test case: uniform random numbers. Time used: 0.084 sec.

4.3. Chirp Signal.

Input
```
chirpneighs<-local.findAllNeighbours(chirptakens,radius=0.6)#0.4
save(chirpneighs, file="chirpneighs.RData")
```

Input
```
load(file="chirpneighs.RData")
local.recurrencePlotAux(chirpneighs)
```

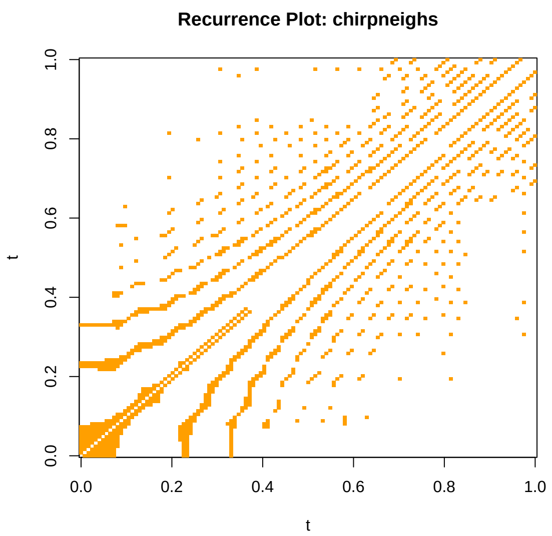

FIGURE 9. Recurrence Plot. Test case: chirp signal. Time used: 0.082 sec.

5. Case Study: Geyser data

This is a classical data set with a two dimensional structure, *waiting* and *waiting*.

ToDo: extend to dimensional

Input
```
library(MASS)
data(faithful)
```

5.1. Geyser Eruptions.

Input
```
plotsignal(faithful$eruptions)
```

See Figure 10,

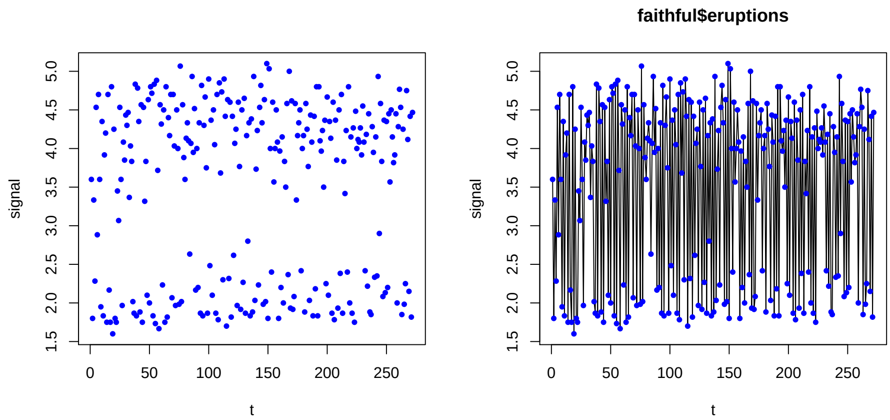

Figure 10. Example case: Old Faithful Geyser eruptions. Signal and linear interpolation.

Input
```
eruptionstakens4 <- local.buildTakens( time.series=faithful$eruptions, embedding.dim=4, time.lag=1)
statepairs(eruptionstakens4)
```

See Figure 11 on the next page

Input
```
eruptionsneighs4<-local.findAllNeighbours(eruptionstakens4, radius=0.8)
save(eruptionsneighs4, file="eruptionsneighs4.RData")
```

Input
```
load(file="eruptionsneighs4.RData")
local.recurrencePlotAux(eruptionsneighs4)
```

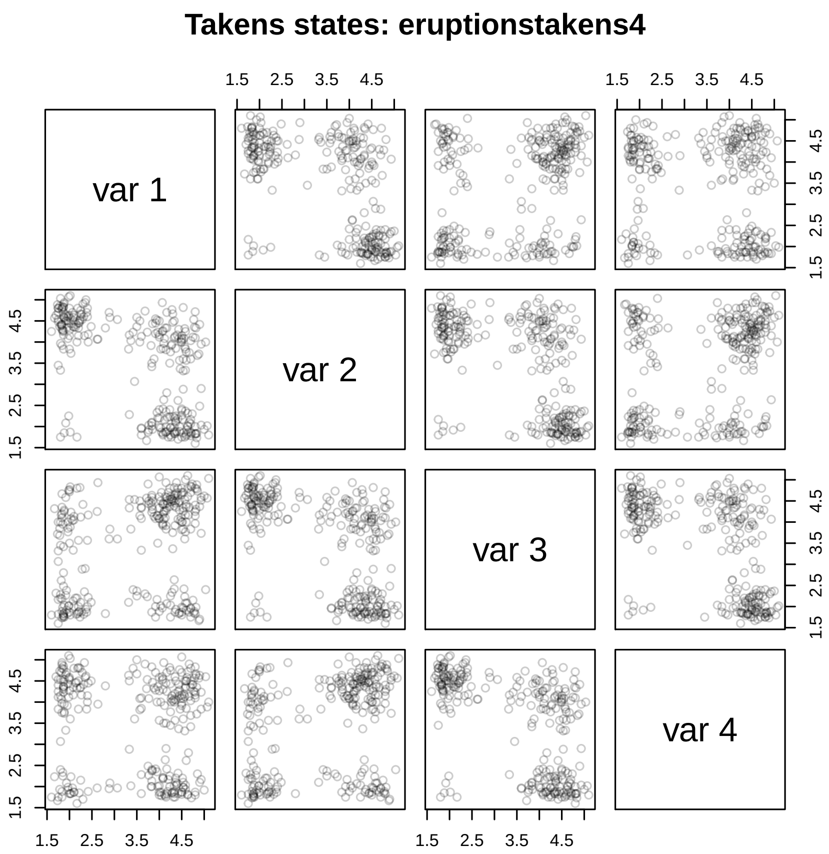

FIGURE 11. Example case: Old Faithful Geyser eruptions. Time used: 0.303 sec.

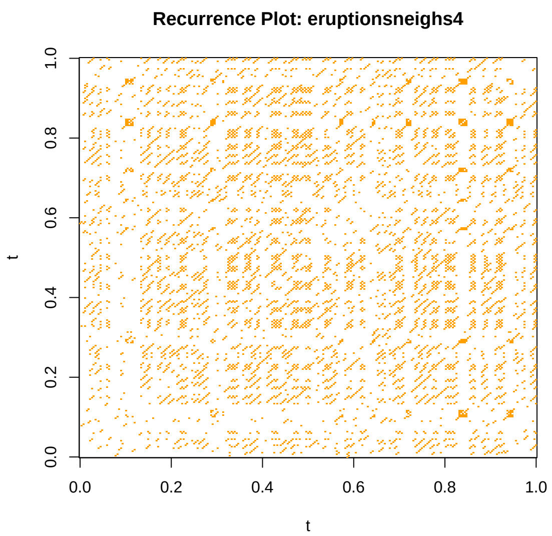

FIGURE 12. Recurrence Plot. Example case: Old Faithful Geyser eruptions. Dim=4. Time used: 0.184 sec.

5.1.1. *Dim=2.*

Input
```
eruptionstakens2 <- local.buildTakens(time.series=faithful$eruptions, embedding.dim=2, time.lag=1)
statepairs(eruptionstakens2)
```

See Figure 13

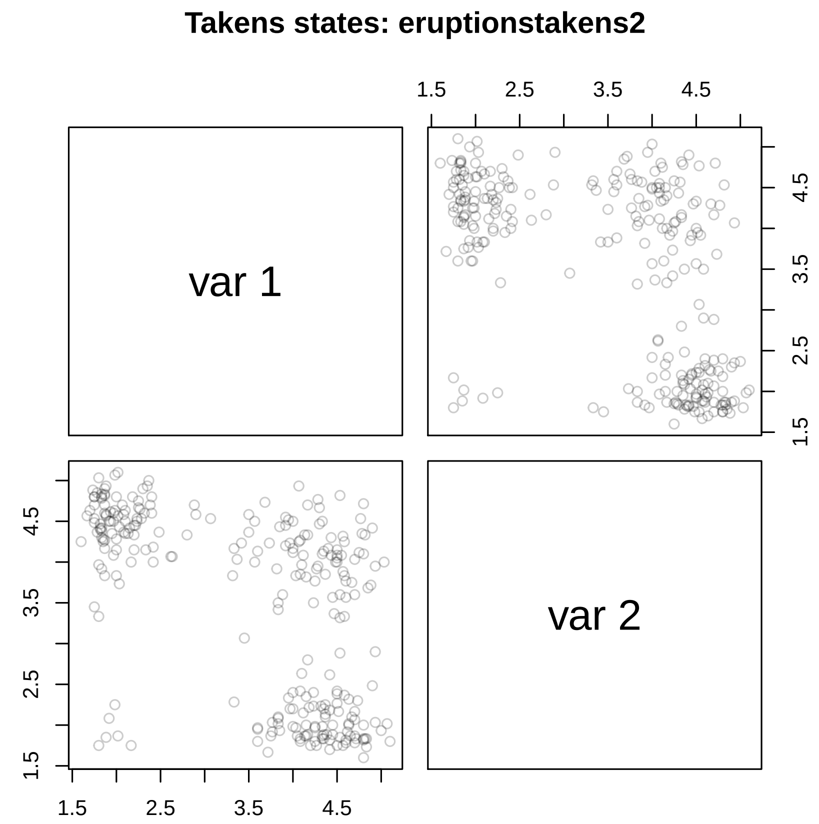

FIGURE 13. Example case: Old Faithful Geyser eruptions. Dim=2. Time used: 0.111 sec.

Input
```
eruptionsneighs2<-local.findAllNeighbours(eruptionstakens2, radius=0.8)
save(eruptionsneighs2, file="eruptionsneighs2.RData")
```

Input
```
load(file="eruptionsneighs2.RData")
local.recurrencePlotAux(eruptionsneighs2)
```

5.1.2. *Dim=6.*

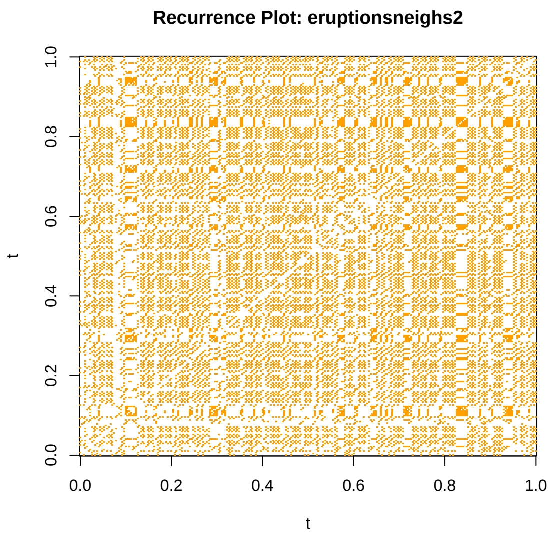

FIGURE 14. Recurrence Plot. Example case: Old Faithful Geyser eruptions. Dim=2. Time used: 0.374 sec.

Input
```
eruptionstakens6 <- local.buildTakens( time.series=faithful$eruptions,embedding.dim=6,time.lag=1)
statepairs(eruptionstakens6)
```

See Figure 15 on the next page

Input
```
eruptionsneighs6<-local.findAllNeighbours(eruptionstakens6, radius=0.8)
save(eruptionsneighs6, file="eruptionsneighs6.RData")
```

Input
```
load(file="eruptionsneighs6.RData")
local.recurrencePlotAux(eruptionsneighs6)
```

5.1.3. *Dim=8.*

Input
```
eruptionstakens8 <- local.buildTakens( time.series=faithful$eruptions,embedding.dim=8,time.lag=1)
statepairs(eruptionstakens8)
```

See Figure 17 on page 16

Input
```
eruptionsneighs8<-local.findAllNeighbours(eruptionstakens8, radius=0.8)
save(eruptionsneighs8, file="eruptionsneighs8.RData")
```

Input

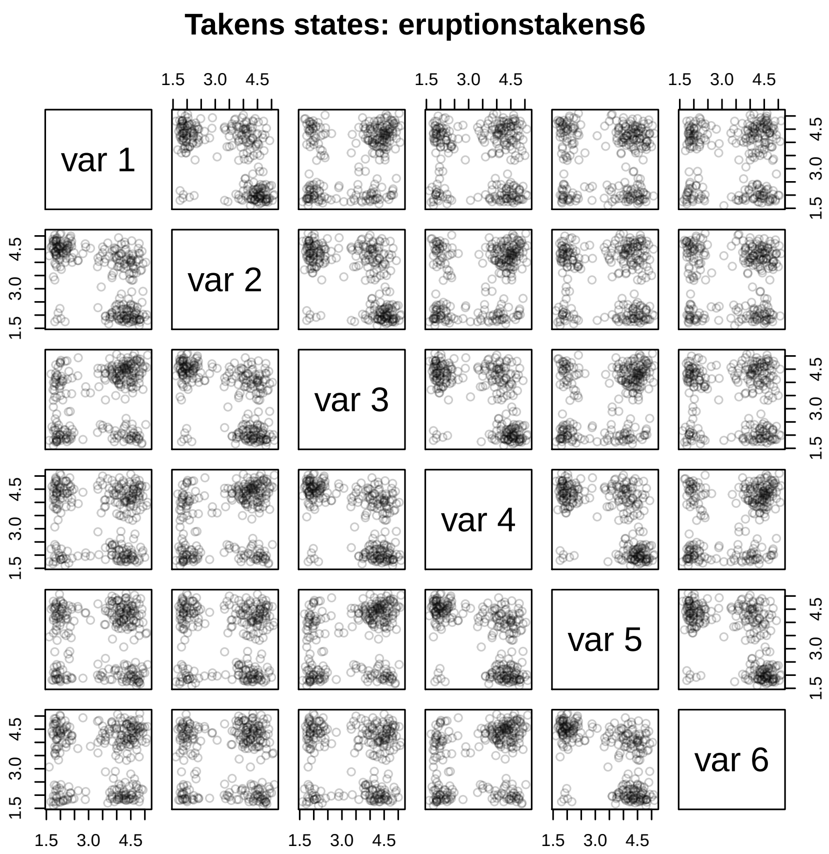

FIGURE 15. Example case: Old Faithful Geyser eruptions. Dim=6. Time used: 0.555 sec.

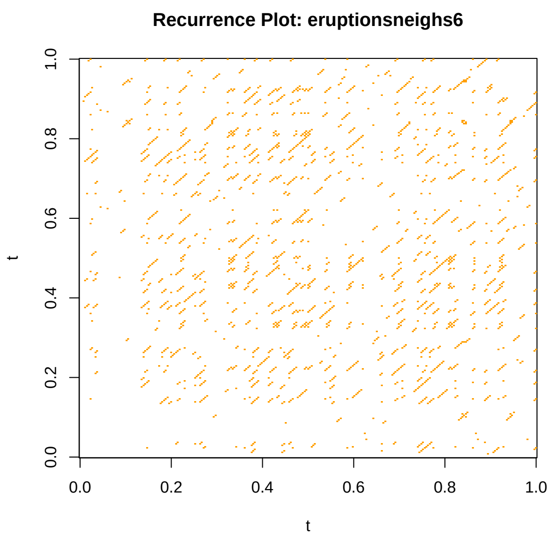

FIGURE 16. Recurrence Plot. Example case: Old Faithful Geyser eruptions. Dim=6. Time used: 0.123 sec.

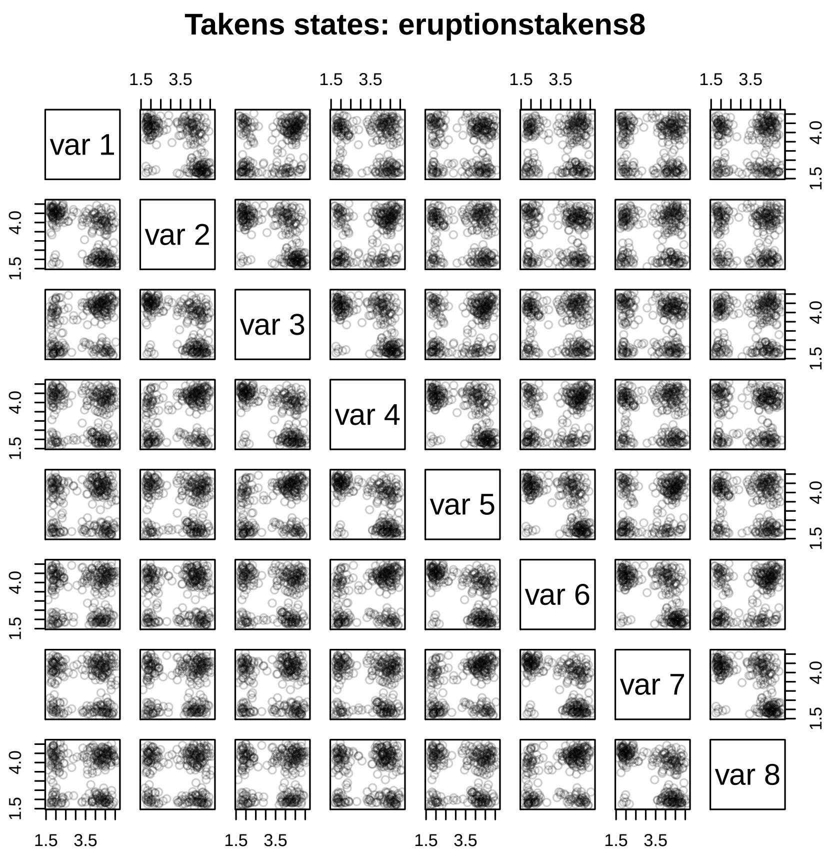

FIGURE 17. Example case: Old Faithful Geyser eruptions. Dim=8. Time used: 0.861 sec.

```
load(file="eruptionsneighs8.RData")
local.recurrencePlotAux(eruptionsneighs8)
```

5.2. **Geyser Eruptions: Comparison by Dimension.** For comparison, recurrence plots for the Geyser data with varying dimension are in Figure 19 on page 18

5.3. **Geyser Waiting.**

Input
```
plotsignal(faithful$waiting)
```

See Figure 20 on page 18,

Input
```
waitingtakens <- local.buildTakens( time.series=faithful$waiting,embedding.dim=4,time.lag=4)
statepairs(waitingtakens)
```

See Figure 21 on page 19

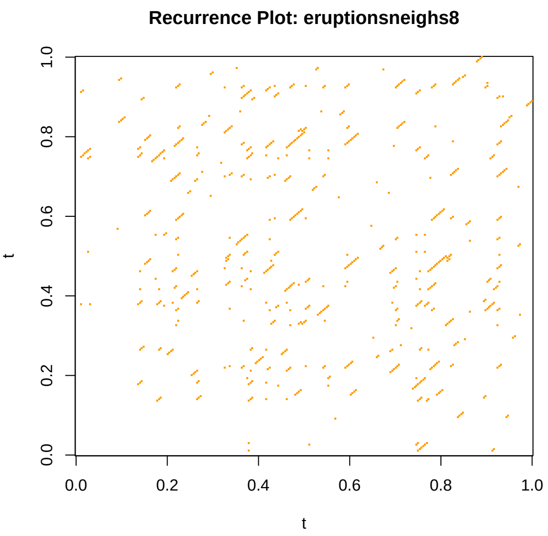

FIGURE 18. Recurrence Plot. Example case: Old Faithful Geyser eruptions. Dim=8. Time used: 0.119 sec.

Input
```
waitingneighs<-local.findAllNeighbours(waitingtakens, radius=16)
save(waitingneighs, file="waitingneighs.Rdata")
```

Input
```
load(file="waitingneighs.RData")
local.recurrencePlotAux(waitingneighs)
```

6. CASE STUDY: HRV DATA

Only 128 da
used in this

Input
```
library(RHRV)
load("/data/pulse/rhrv/pkg/data/HRVData.rda")
load("/data/pulse/rhrv/pkg/data/HRVProcessedData.rda")
###################################################
### code chunk number 1: creation
###################################################
hrv.data  = CreateHRVData()
hrv.data = SetVerbose(hrv.data, TRUE )
###################################################
### code chunk number 3: loading
###################################################
hrv.data = LoadBeatAscii(hrv.data, "example.beats",
       RecordPath = "/data/pulse/rhrv/tutorial/beatsFolder")
```

Output
```
** Loading beats positions for record: example.beats **
   Path: /data/pulse/rhrv/tutorial/beatsFolder
   Scale: 1
   Date: 01/01/1900
```

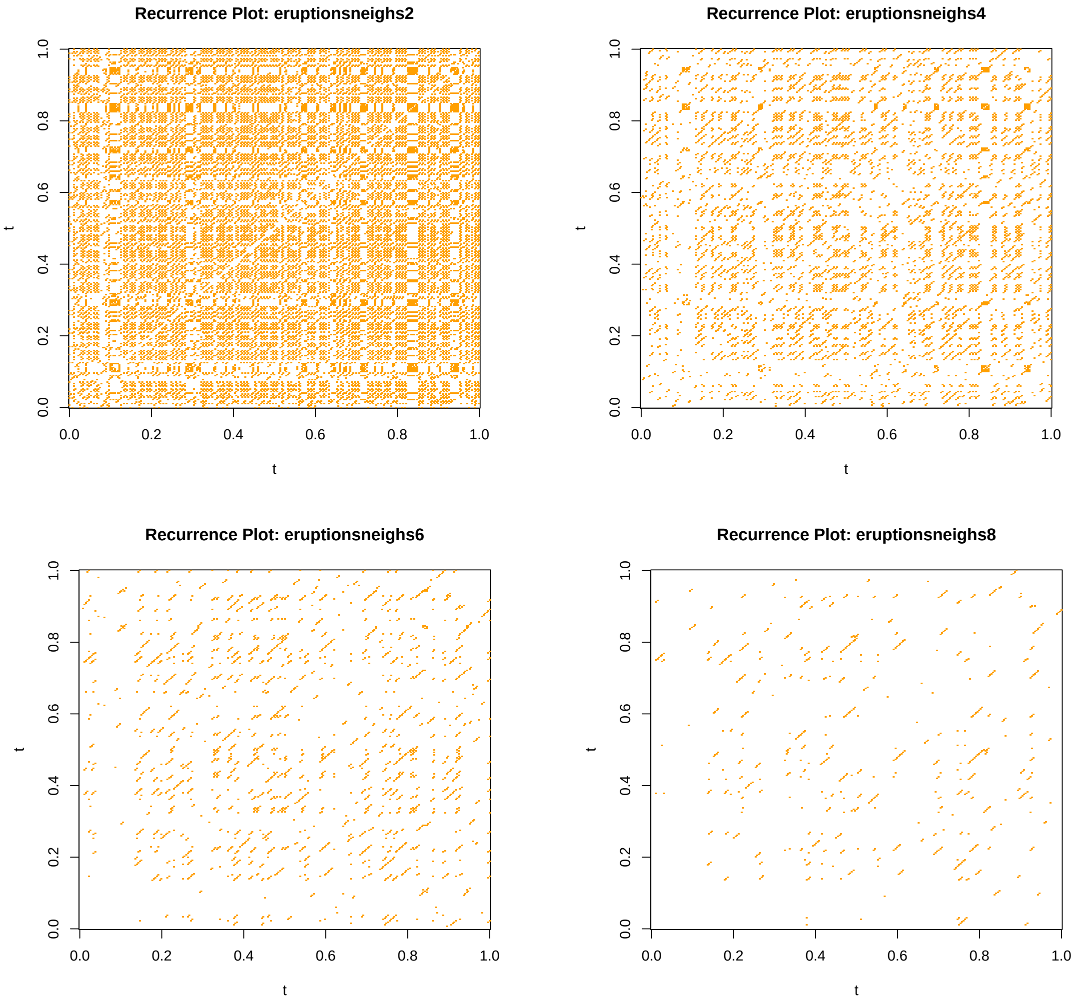

FIGURE 19. Recurrence Plot. Example case: Old Faithful Geyser eruptions. Dim=2, 4, 6, 8.

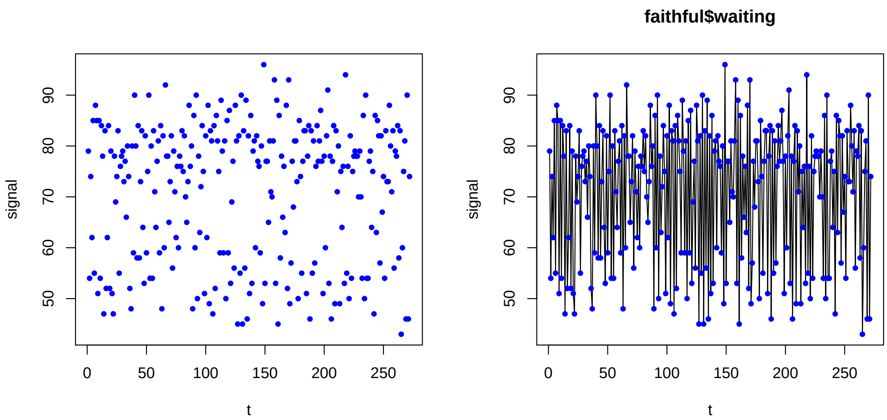

FIGURE 20. Example case: Old Faithful Geyser waiting. Signal and linear interpolation. Time used: 0.324 sec.

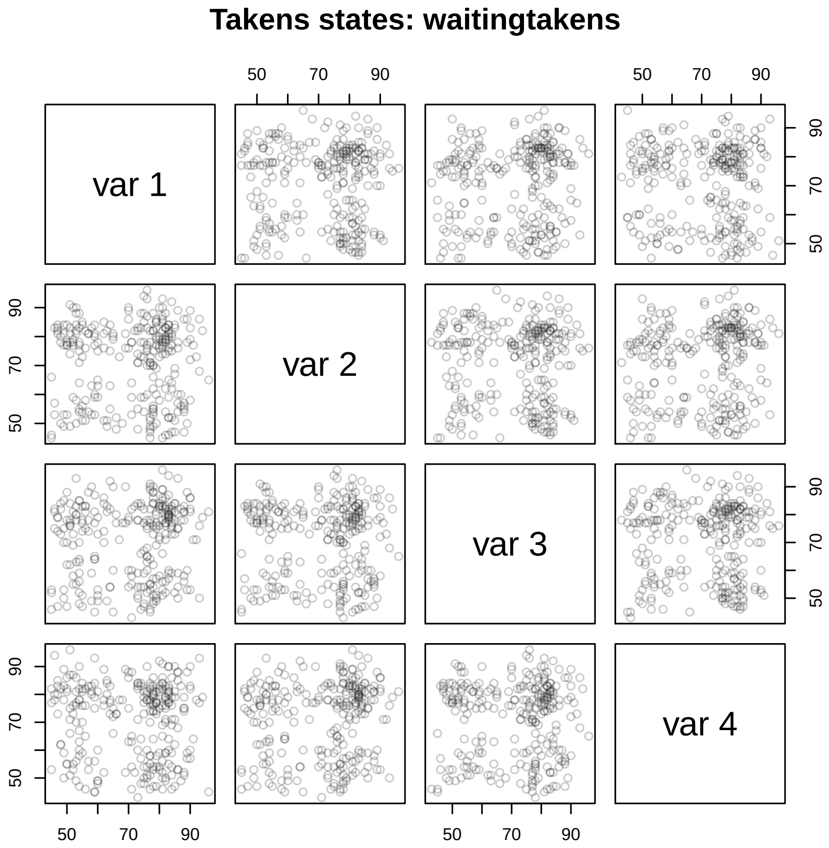

FIGURE 21. Example case: Old Faithful Geyser waiting. Time used: 0.257 sec.

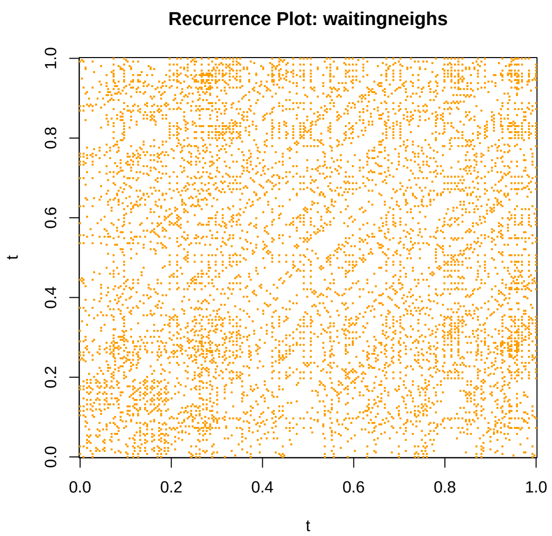

FIGURE 22. Recurrence Plot. Example case: Old Faithful Geyser waiting. Time used: 0.186 sec.

```
   Time: 00:00:00
   Number of beats: 17360
```

Input

```
 #       RecordPath = "beatsFolder")


 ###################################################
 ### code chunk number 4: derivating
 ###################################################
 hrv.data = BuildNIHR(hrv.data)
```

Output

```
** Calculating non-interpolated heart rate **
   Number of beats: 17360
```

Input

Input

```
 plotsignal(hrv.data$Beat$RR)
```

ToDo: We have outlies at approximately 2*RR. Could this be an artefact of preprocessing, filtering out too many impulses?

See Figure 23,

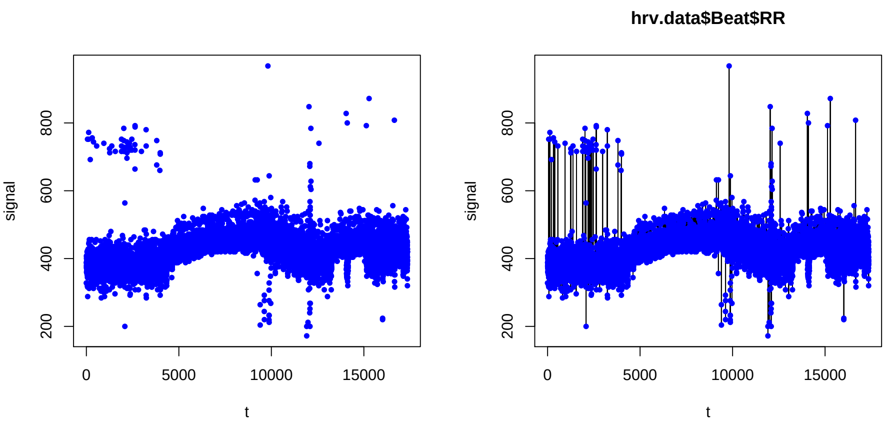

FIGURE 23. Example case: RHRV tutorial. Signal and linear interpolation.

Input

```
 hrvRRtakens4 <- local.buildTakens( time.series=hrv.data$Beat$RR[1:nsignal],embedding.dim=4,time.lag=1)
 statepairs(hrvRRtakens4)
```

See Figure 24 on the next page

Input

```
 statepairs(hrvRRtakens4, rank=TRUE)
```

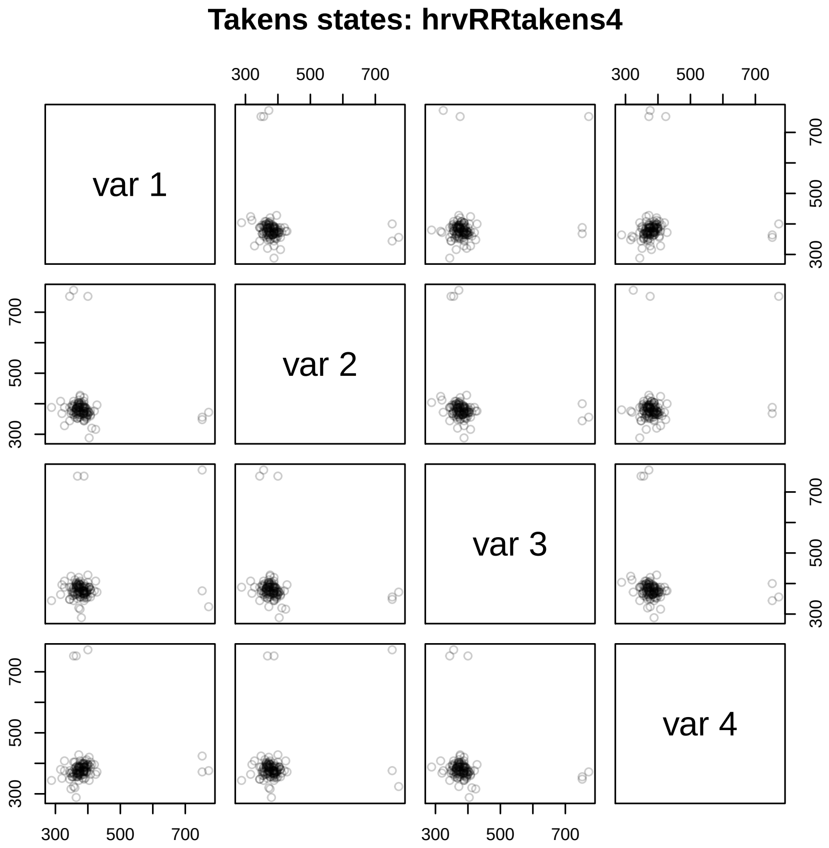

FIGURE 24. Example case: RHRV tutorial. Time used: 0.16 sec.

See Figure 25 on the following page

Input
```
hrvRRneighs4 <-local.findAllNeighbours(hrvRRtakens4, radius=16)
save(hrvRRneighs4, file="hrvRRneighs4.Rdata")
```

Time used: 0.036 sec.

Input
```
load(file="hrvRRneighs4.RData")
local.recurrencePlotAux(hrvRRneighs4)
```

We should the breathin so a time la order of 10 expected.

6.1. **RHRV: Comparison by Dimension.**

Input
```
hrvRRtakens2 <- local.buildTakens( time.series=hrv.data$Beat$RR[1:nsignal],embedding.dim=2,time.lag=1)
hrvRRneighs2 <-local.findAllNeighbours(hrvRRtakens2, radius=16)
save(hrvRRneighs2, file="hrvRRneighs2.Rdata")
```

Time used: 0.042 sec.

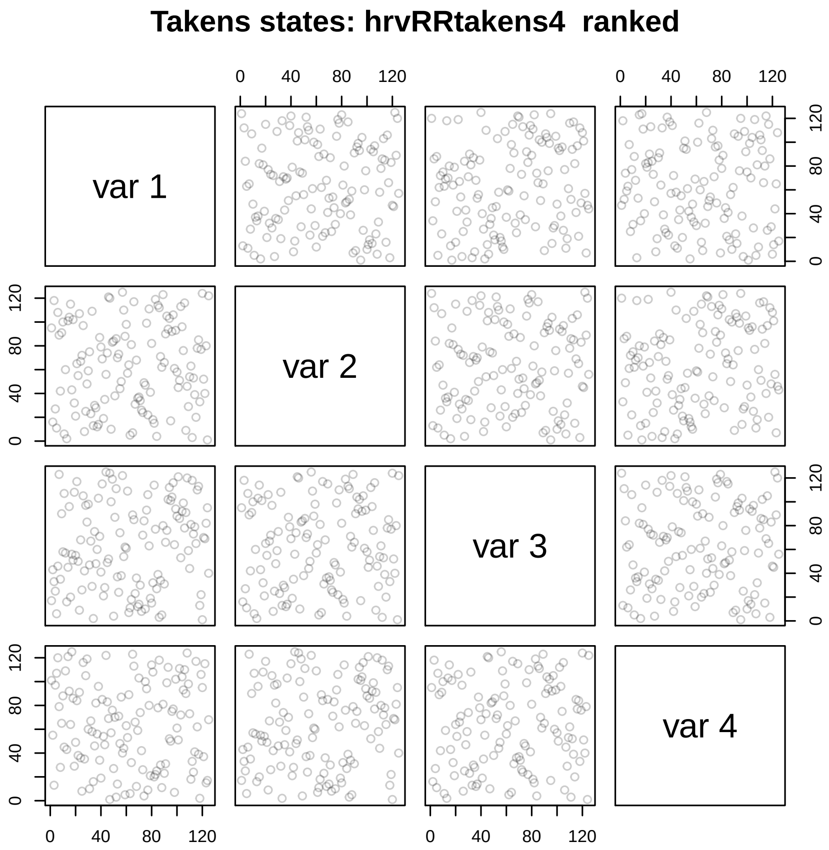

FIGURE 25. Example case: RHRV tutorial. Ranked data. Time used: 0.38 sec.

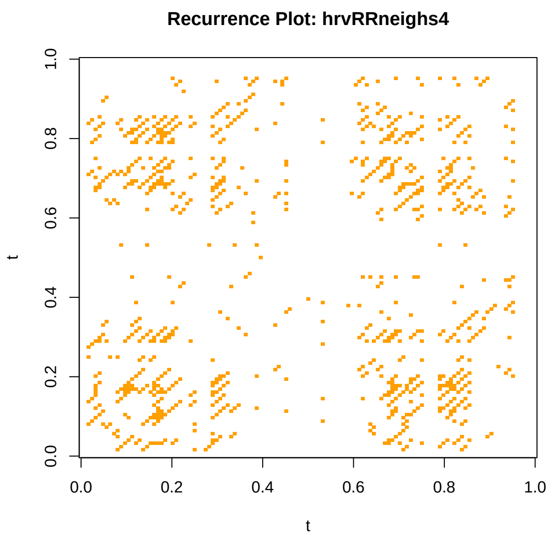

FIGURE 26. Recurrence Plot. Example case: RHRV tutorial. Dim=4. Time used: 0.106 sec.

Input
```
load(file="hrvRRneighs2.RData")
local.recurrencePlotAux(hrvRRneighs2)
```

Time used: 0.125 sec.

Input
```
hrvRRtakens6 <- local.buildTakens( time.series=hrv.data$Beat$RR[1:nsignal],embedding.dim=6,time.lag=1)
hrvRRneighs6 <-local.findAllNeighbours(hrvRRtakens6, radius=16)
save(hrvRRneighs6, file="hrvRRneighs6.Rdata")
```

Time used: 0.035 sec.

Input
```
load(file="hrvRRneighs6.RData")
local.recurrencePlotAux(hrvRRneighs6)
```

Dim=6. Time used: 0.089 sec.

Input
```
hrvRRtakens8 <- local.buildTakens( time.series=hrv.data$Beat$RR[1:nsignal],embedding.dim=8,time.lag=1)
hrvRRneighs8 <-local.findAllNeighbours(hrvRRtakens8, radius=32)
save(hrvRRneighs8, file="hrvRRneighs8.Rdata")
```

Time used: 0.04 sec.

Input
```
load(file="hrvRRneighs8.RData")
local.recurrencePlotAux(hrvRRneighs8)
```

Dim=8. Time used: 0.124 sec.

Input
```
hrvRRtakens12 <- local.buildTakens( time.series=hrv.data$Beat$RR[1:nsignal],embedding.dim=2,time.lag=1)
hrvRRneighs12 <-local.findAllNeighbours(hrvRRtakens12, radius=16)
save(hrvRRneighs12, file="hrvRRneighs12.Rdata")
```

Time used: 0.184 sec.

Input
```
load(file="hrvRRneighs12.RData")
local.recurrencePlotAux(hrvRRneighs12)
```

Time used: 0.13 sec.

Input
```
hrvRRtakens16 <- local.buildTakens( time.series=hrv.data$Beat$RR[1:nsignal],embedding.dim=16,time.lag=1)
hrvRRneighs16 <-local.findAllNeighbours(hrvRRtakens16, radius=32)
save(hrvRRneighs16, file="hrvRRneighs16.Rdata")
```

Time used: 0.188 sec.

Input
```
load(file="hrvRRneighs16.RData")
local.recurrencePlotAux(hrvRRneighs16)
```

Time used: 0.107 sec.

ToDo: Consider using differences

6.2. **Hart Rate Variation.** Since we are not interested in heart rate (or pulse), but in heart rate variation, a proposal is to use scaled differences.

Input
```
# source('/data/pulse/rhrv/pkg/R/BuildNIHR2.R', chdir = TRUE)
BuildNIDHR <-
function(HRVData, verbose=NULL) {
#------------------------------------------------------
# Obtains instantaneous heart rate variation from beats positions
# D for difference
#------------------------------------------------------
        if (!is.null(verbose)) {
                cat("  --- Warning: deprecated argument, using SetVerbose() instead ---\n    --- See hel
                SetVerbose(HRVData,verbose)
        }

        if (HRVData$Verbose) {
                cat("** Calculating non-interpolated heart rate differences **\n")
        }

        if (is.null(HRVData$Beat$Time)) {
                cat("   --- ERROR: Beats positions not present... Impossible to calculate Heart Rate!! -
                return(HRVData)
        }

        NBeats=length(HRVData$Beat$Time)
        if (HRVData$Verbose) {
                cat("   Number of beats:",NBeats,"\n");
        }

  # addition gs
   #using NA, not constant extrapolation as else in RHRV
   #drr=c(NA,NA,1000.0*        diff(HRVData$Beat$Time, lag=1 , differences=2))
   HRVData$Beat$dRR=c(NA, NA,
           1000.0*diff(HRVData$Beat$Time, lag=1, differences=2))

   HRVData$Beat$avRR=(c(NA,HRVData$Beat$RR[-1])+HRVData$Beat$RR)/2

   HRVData$Beat$HRRV <- HRVData$Beat$dRR/HRVData$Beat$avRR

        return(HRVData)
}
```

differences for HRV

Input
```
hrv.data <- BuildNIDHR(hrv.data)
```

Output
```
** Calculating non-interpolated heart rate differences **
   Number of beats: 17360
```

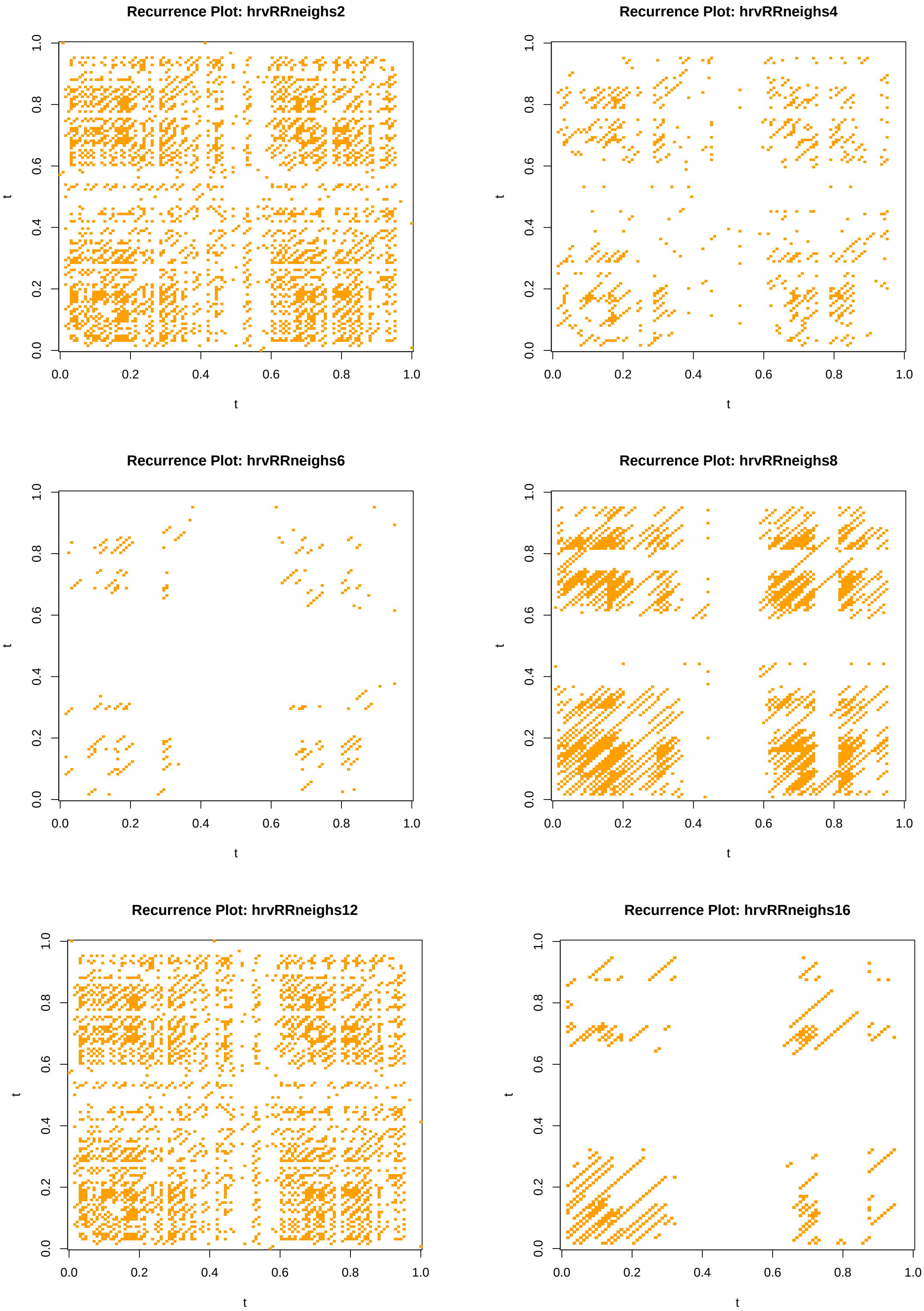

FIGURE 27. Recurrence Plot. Example case: RHRV tutorial. Dim=2, 4, 6, 8, 12, 16. Time used: 0.108 sec.

Input
```
HRRV <- hrv.data$Beat$HRRV
```

These are the displays we used before, now for HRRV:

Input
```
plotsignal(HRRV)
```

See Figure 28,

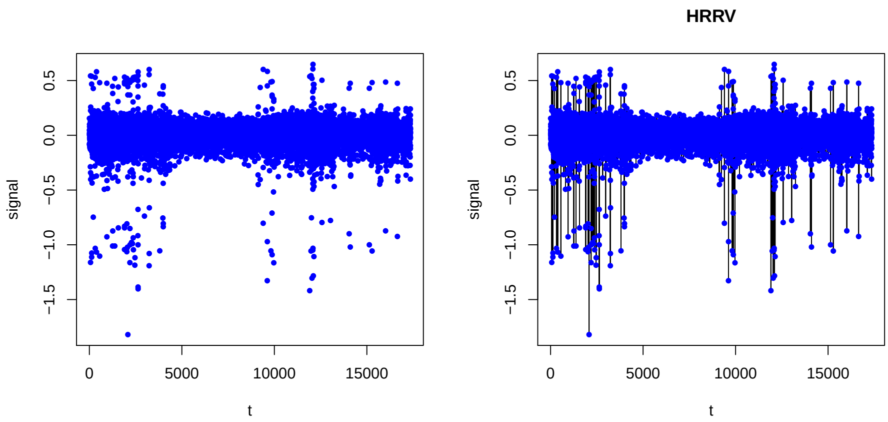

FIGURE 28. Example case: RHRV tutorial. HRRV Signal and linear interpolation.

Only 128 data points used in this section

Input
```
hrvRRVtakens4 <- local.buildTakens( time.series=HRRV[1:nsignal], embedding.dim=4,time.lag=1)
statepairs(hrvRRVtakens4)
```

See Figure 29 on the facing page

Input
```
statepairs(hrvRRVtakens4, rank=TRUE)
```

ToDo: findAllNeighbours does not handle NAs

See Figure 30 on page 28

Input
```
#use hack: findAllNeighbours does not handle NAs}
hrvRRVneighs4 <-local.findAllNeighbours(hrvRRVtakens4[-(1:2),],, radius=0.25)
save(hrvRRVneighs4, file="hrvRRVneighs4.Rdata")
```

Time used: 0.022 sec.

Input
```
load(file="hrvRRVneighs4.RData")
local.recurrencePlotAux(hrvRRVneighs4)
```

ToDo: check. There seem to be strange artefacts.

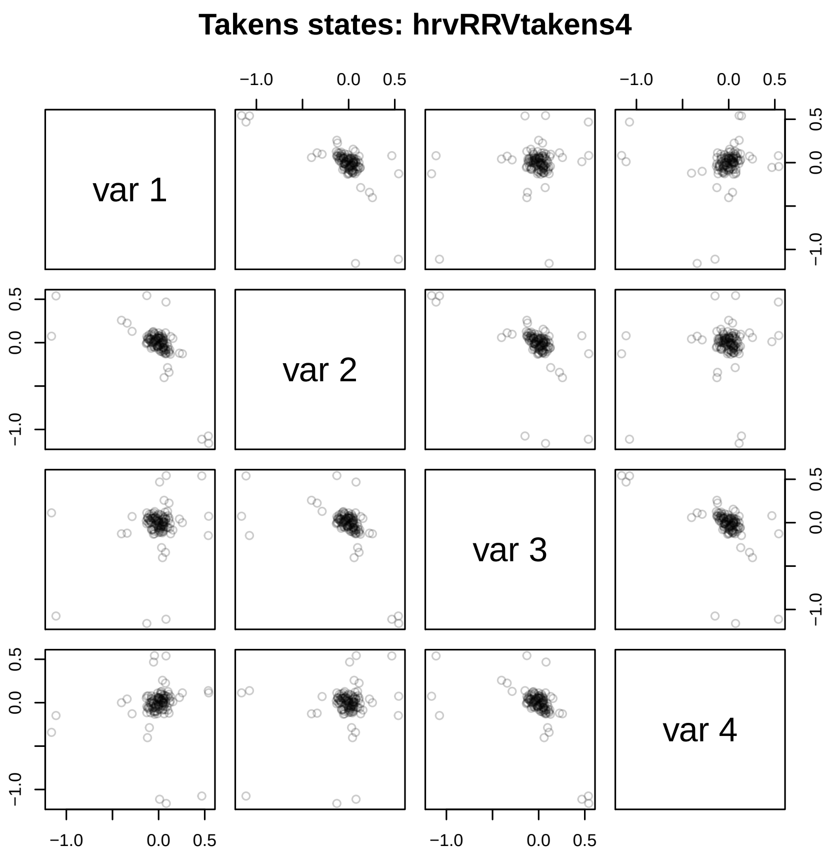

FIGURE 29. Example case: RHRV tutorial. HRRV Time used: 0.204 sec.

6.3. RHRV: Variation :Comparison by Dimension.

We should expect the breathing rhythm, so a time lag in the order of 10 is to be expected.

ToDo: fix default setting for radius. Eckmann uses NN=10

Input
```
hrvRRVtakens2 <- local.buildTakens( time.series=HRRV[1:nsignal],embedding.dim=2,time.lag=1)
hrvRRVneighs2 <-local.findAllNeighbours(hrvRRVtakens2[-(1:2),], radius=0.25)
save(hrvRRVneighs2, file="hrvRRVneighs2.Rdata")
```

Time used: 0.042 sec.

Input
```
load(file="hrvRRVneighs2.RData")
local.recurrencePlotAux(hrvRRVneighs2)
```

Time used: 0.278 sec.

Input
```
hrvRRVtakens6 <- local.buildTakens( time.series=HRRV[1:nsignal],embedding.dim=6,time.lag=1)
hrvRRVneighs6 <-local.findAllNeighbours(hrvRRVtakens6[-(1:2),], radius=0.25)
save(hrvRRVneighs6, file="hrvRRVneighs6.Rdata")
```

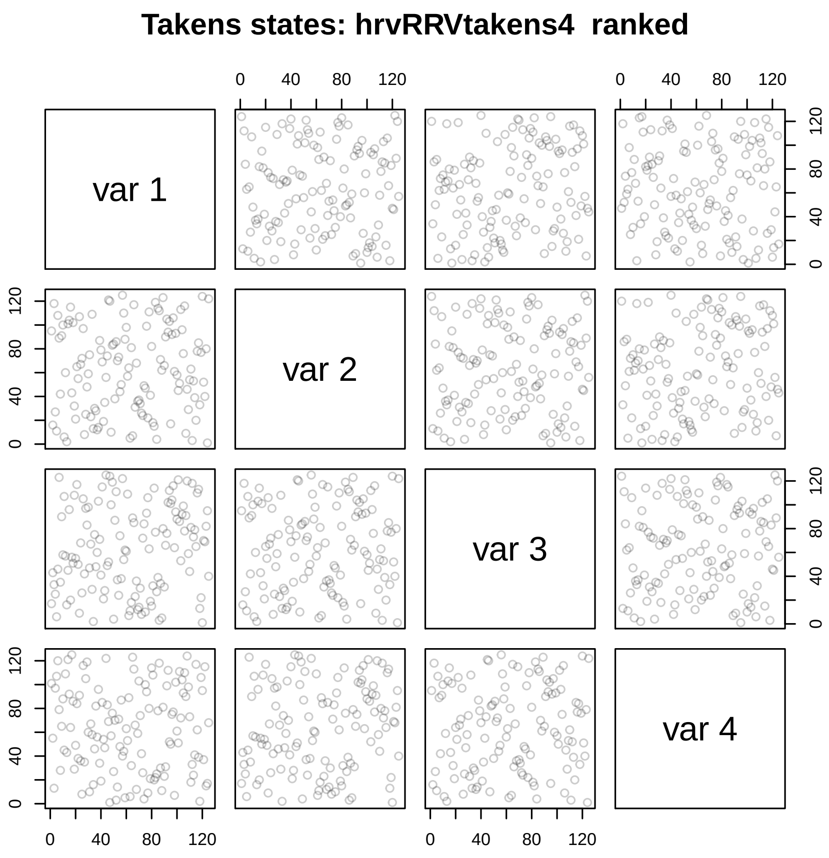

FIGURE 30. Example case: RHRV tutorial. Ranked HRRV data. Time used: 0.451 sec.

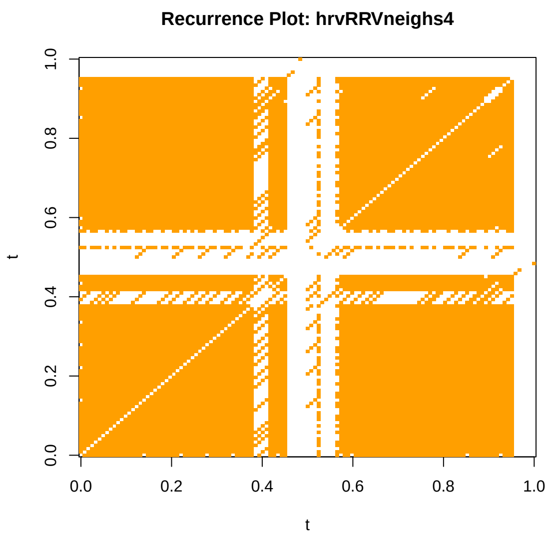

FIGURE 31. Recurrence Plot. Example case: RHRV tutorial. HRRV Dim=4. Time used: 0.219 sec.

Time used: 0.066 sec.

Input
```
load(file="hrvRRVneighs6.RData")
local.recurrencePlotAux(hrvRRVneighs6)
```

Dim=6. Time used: 0.203 sec.

Input
```
hrvRRVtakens8 <- local.buildTakens( time.series=HRRV[1:nsignal],embedding.dim=8,time.lag=1)
hrvRRVneighs8 <-local.findAllNeighbours(hrvRRVtakens8[-(1:2),], radius=0.25)
save(hrvRRVneighs8, file="hrvRRVneighs8.Rdata")
```

Time used: 0.048 sec.

Input
```
load(file="hrvRRVneighs8.RData")
local.recurrencePlotAux(hrvRRVneighs8)
```

Dim=8. Time used: 0.206 sec.

Input
```
hrvRRVtakens12 <- local.buildTakens( time.series=HRRV[1:nsignal],embedding.dim=2,time.lag=1)
hrvRRVneighs12 <-local.findAllNeighbours(hrvRRVtakens12[-(1:2),], radius=0.25)
save(hrvRRVneighs12, file="hrvRRVneighs12.Rdata")
```

Time used: 0.266 sec.

Input
```
load(file="hrvRRVneighs12.RData")
local.recurrencePlotAux(hrvRRVneighs12)
```

Time used: 0.259 sec.

Input
```
hrvRRVtakens16 <- local.buildTakens( time.series=HRRV[1:nsignal],embedding.dim=16,time.lag=1)
hrvRRVneighs16 <-local.findAllNeighbours(hrvRRVtakens16[-(1:2),], radius=0.25)
save(hrvRRVneighs16, file="hrvRRVneighs16.Rdata")
```

Time used: 0.305 sec.

Input
```
load(file="hrvRRVneighs16.RData")
local.recurrencePlotAux(hrvRRVneighs16)
```

Time used: 0.17 sec.

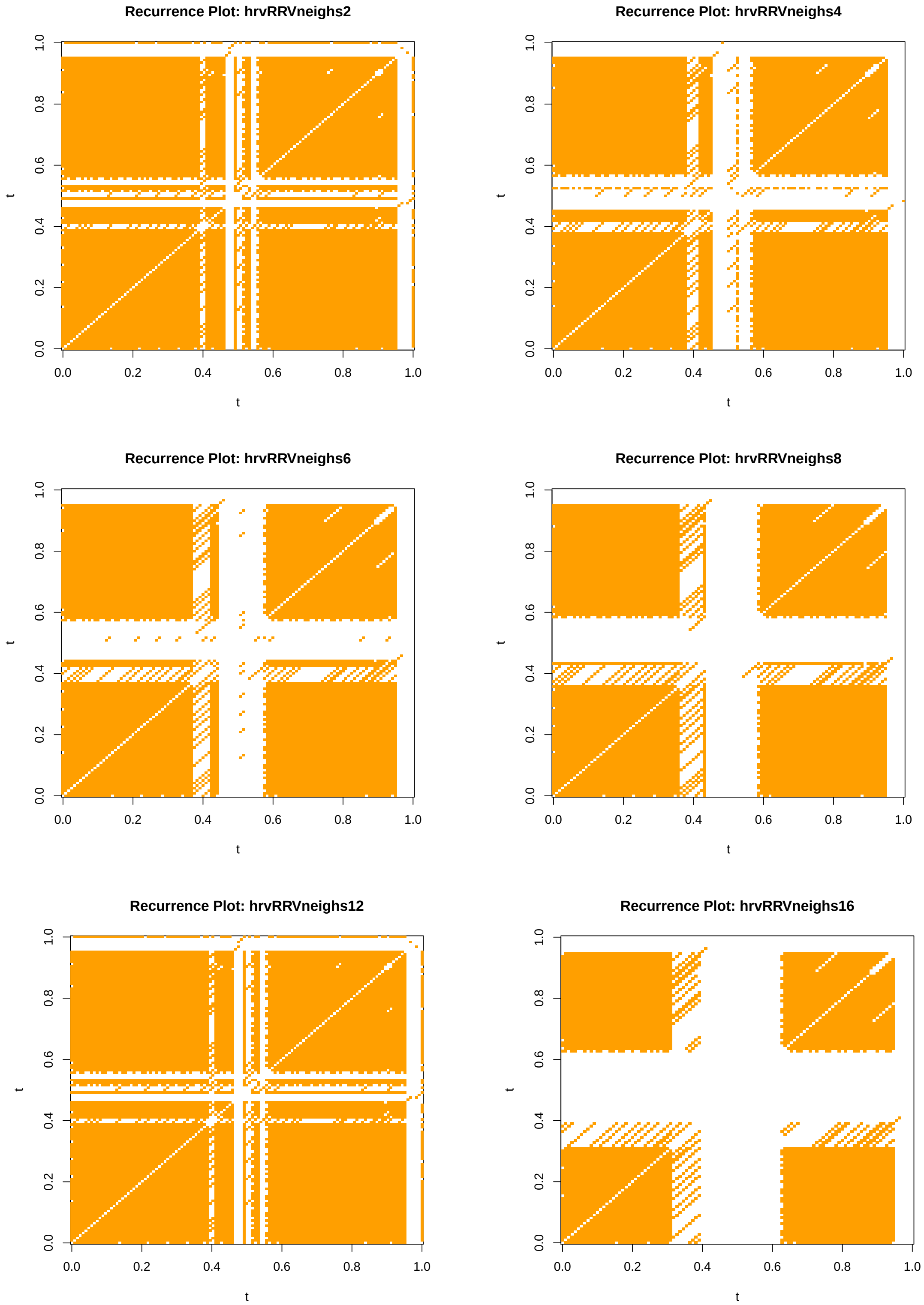

FIGURE 32. Recurrence Plot. Example case: RHRV tutorial. Dim=2, 4, 6, 8, 12, 16. Time used: 0.17 sec.

References

Eckmann, Jean-Pierre, Kamphorst, S Oliffson, & Ruelle, David. 1987. Recurrence plots of dynamical systems. *Europhys. Lett*, **4**(9), 973–977.

Index

R session info:

Total Sweave time used: 11.893 sec. at Mon Feb 10 16:49:55 2014.

- R version 3.0.2 (2013-09-25), x86_64-apple-darwin10.8.0
- Locale: en_GB.UTF-8/en_GB.UTF-8/en_GB.UTF-8/C/en_GB.UTF-8/en_GB.UTF-8
- Base packages: base, datasets, graphics, grDevices, methods, stats, tcltk, utils
- Other packages: leaps 2.9, locfit 1.5-9.1, MASS 7.3-29, Matrix 1.1-2, mgcv 1.7-27, nlme 3.1-113, nonlinearTseries 0.2, rgl 0.93.996, RHRV 4.0, sintro 0.1-3, tkrplot 0.0-23, TSA 1.01, tseries 0.10-32, waveslim 1.7.3
- Loaded via a namespace (and not attached): grid 3.0.2, lattice 0.20-25, quadprog 1.5-5, tools 3.0.2, zoo 1.7-11

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textheight: 9.21922in

CVS/Svn repository information:

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$HeadURL: /u/math/j40/cvsroot/lectures/src/dataanalysis/Rnw/recurrence.Rnw,v $

$Revision: 1.2 $

$Date: 2014/02/05 20:05:07 $

$name: $

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