



Digital biosignal processing with R

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Data science?

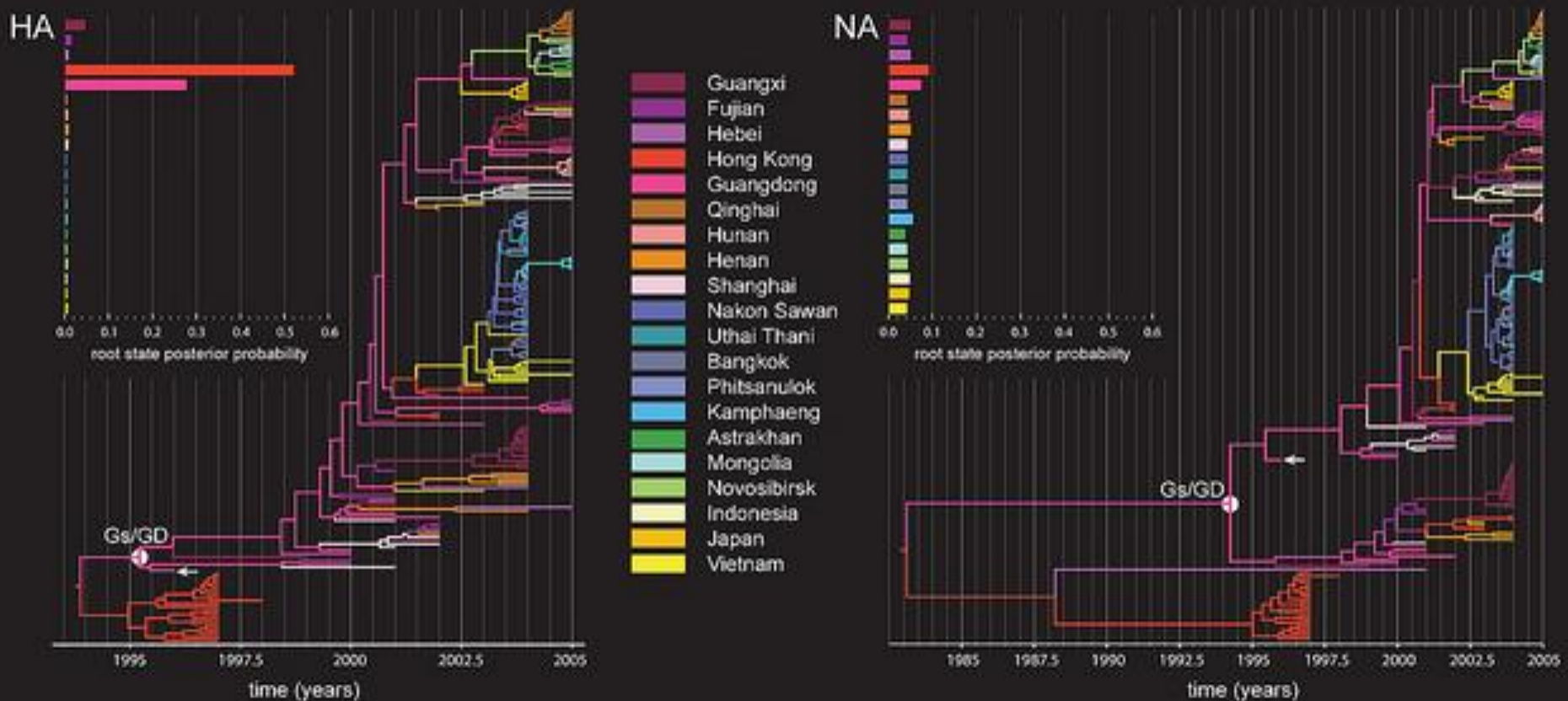
- Familiar with this term?
- This presentation is not about data science.
- Surprisingly.
- But it's related.
- Not surprisingly.



Bioinformatics?

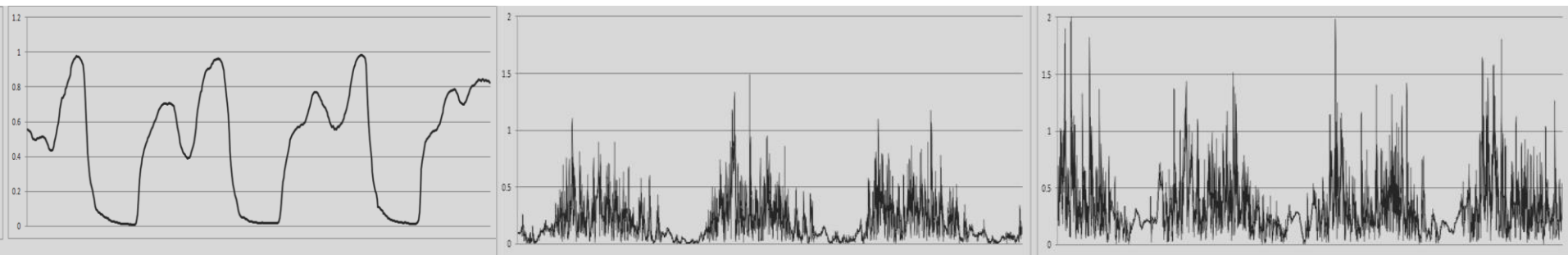
- No.
- Not this time.

Image:Phylogeny figures, Flickr: <https://www.flickr.com/photos/123636286@N02/14138128772/>



Biosignal processing

- R is suitable for signal processing.
- Actually, R provides strong foundation for application of signal processing.
- It is useful and in some cases irreplaceable as an initial step before machine learning application or even feature extraction.
- “Signal” package since 2013: signal developers (2013). signal: Signal processing. URL: <http://r-forge.r-project.org/projects/signal/>.
- Functions are originally written for Matlab and GNU Octave. All functions are “styled” in reference to Matlab.
- Good or bad? At least, not ugly.

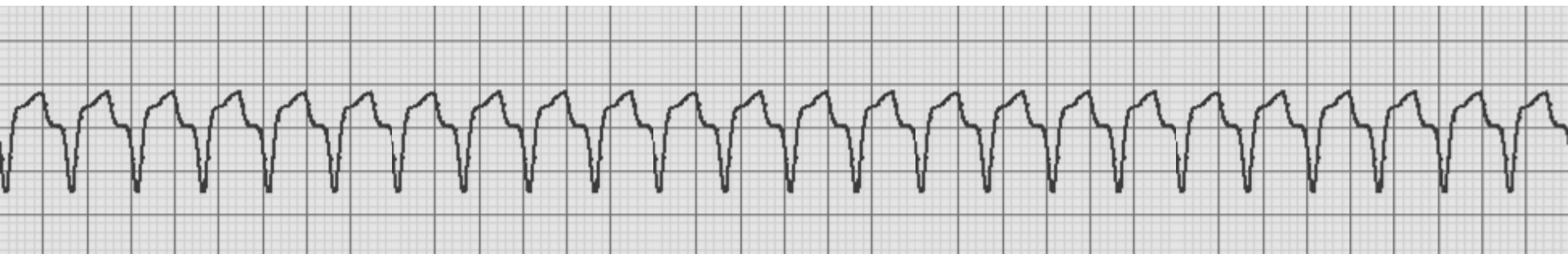


Other CRAN packages

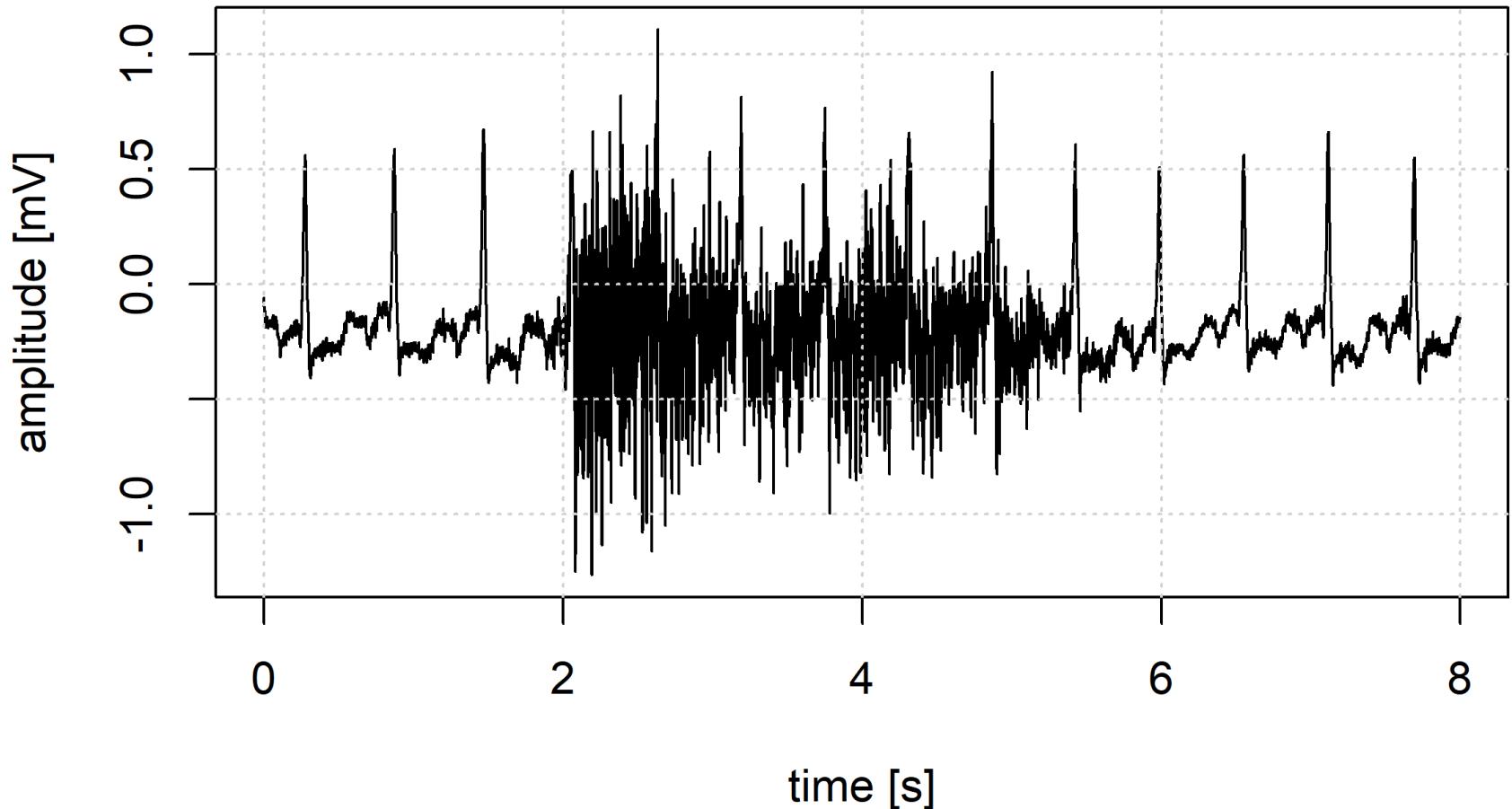
- wavelets
- RHRV
- erpR
- eegkit
- biosignalEMG
- zoo
- e1071
- ...

Signal vs. biosignal

- “A biosignal is any signal in living beings that can be continually measured and monitored.”, [Online] <https://en.wikipedia.org/wiki/Biosignal>, Assessed October 25, 2018.
- It usually refers to electrical biosignals.
 - EMG, ECG, EEG, EGG, ENG... familiar?
- All these signals are very sensitive to artifacts (can be influenced by many factors such as power hum, cell phone, movements, other biosignals, contacts, ...).
- Artifact cancellation is a must!

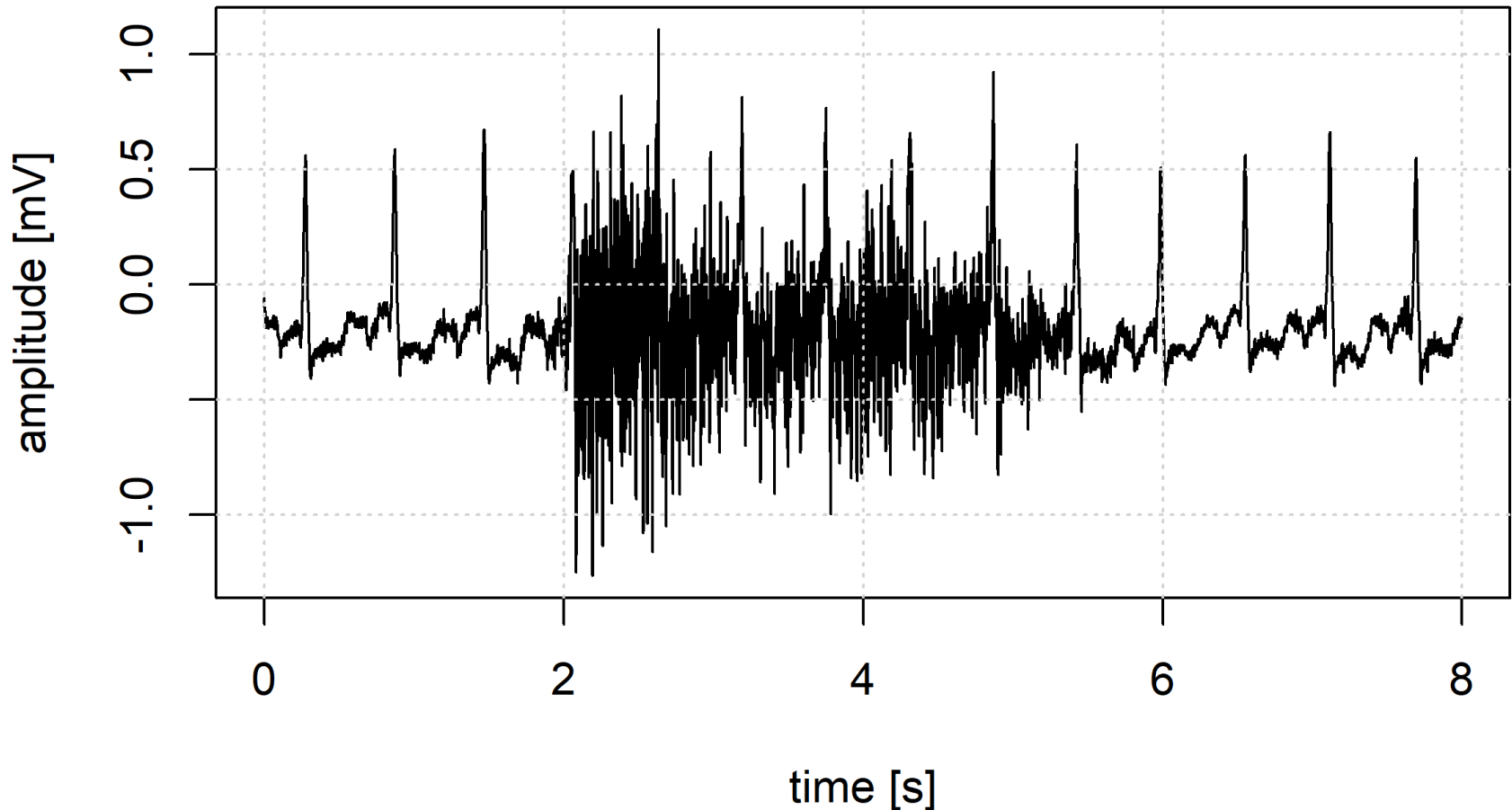


What is “signal” and where is “noise”?



What is “signal” and where is “noise”?

EMG signal (Pectoralis muscle)

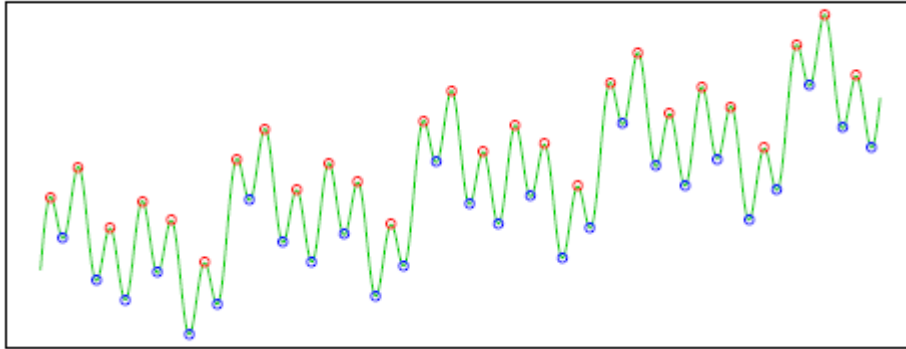


EMD

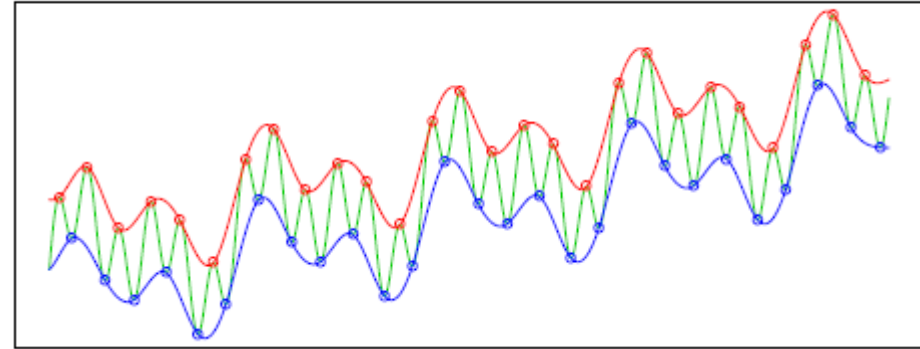
- Empirical Mode Decomposition
- Nonstationary and nonlinear processes can be analyzed with EMD (basically, you can use it to solve very complex tasks... biosignals?).
- EMD can be used for filtering too.
- Relatively new method (1998):
 - Huang NE, Shen Z, Long SR, Wu MC, Shih HH, Zheng Q, Yen NC, Tung CC, Liu HH. The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. *In Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, 1998 (Vol. 454, No. 1971, pp. 903-995). The Royal Society.

Sifting iterative procedure

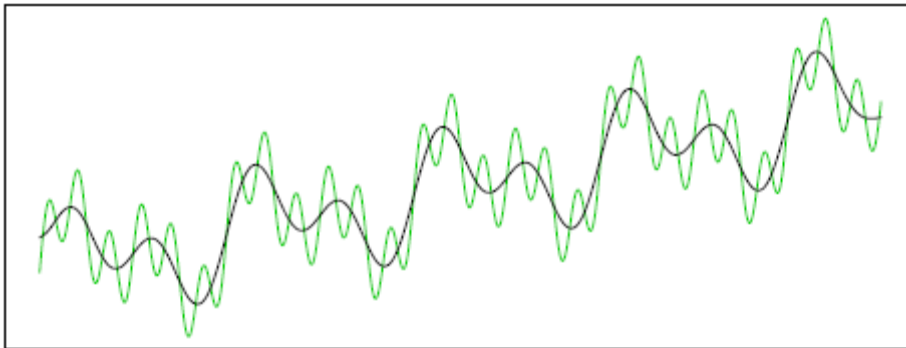
(a)



(b)



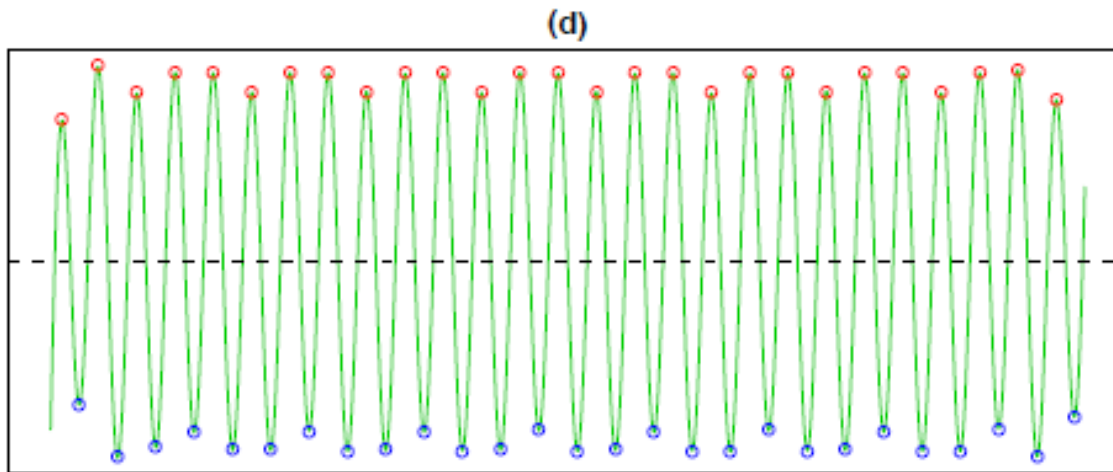
(c)



Modified image from Kim, Donghoh, and Hee-Seok Oh. "EMD: a package for empirical mode decomposition and Hilbert spectrum." *The R Journal* 1.1 (2009): 40-46, <https://journal.r-project.org/archive/2009/RJ-2009-002/RJ-2009-002.pdf>.

- a) Define local extrema
- b) Define upper and lower envelopes by interpolation
- c) Take average of upper and lower components

Not done yet!

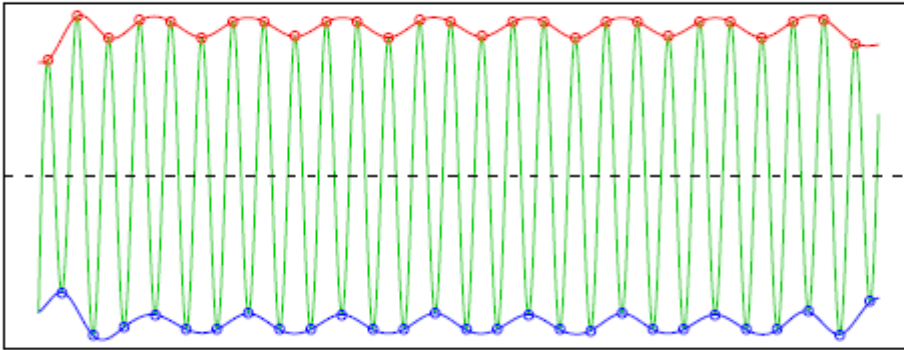


Modified image from Kim, Donghoh, and Hee-Seok Oh. "EMD: a package for empirical mode decomposition and Hilbert spectrum." *The R Journal* 1.1 (2009): 40-46, <https://journal.r-project.org/archive/2009/RJ-2009-002/RJ-2009-002.pdf>.

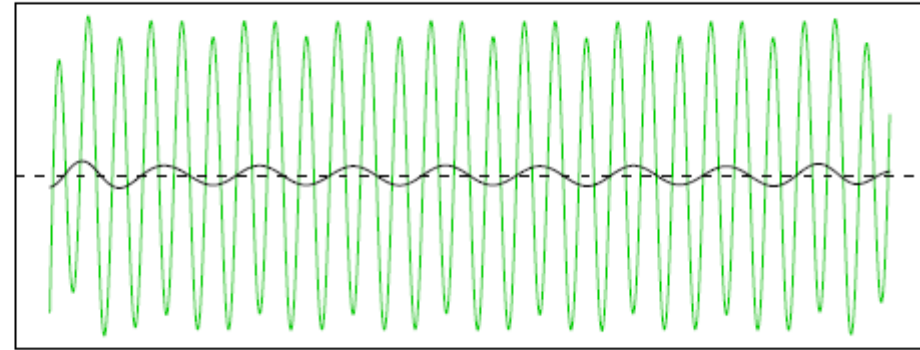
- d) Subtract average from c) from the original signal and then check if it is an IMF:
1. The number of extrema and the number of zero-crossings differs only by one.
 2. The local average is zero (maximums and minimums are symmetrical)

And iterations ...

(e)



(f)



Modified image from Kim, Donghoh, and Hee-Seok Oh. "EMD: a package for empirical mode decomposition and Hilbert spectrum." *The R Journal* 1.1 (2009): 40-46, <https://journal.r-project.org/archive/2009/RJ-2009-002/RJ-2009-002.pdf>.

- e) If the resulting time series is not an IMF, you should continue.
- f) Procedure (with upper and lower envelopes, and their average subtracted from the signal) repeats until you spot an IMF.

There are many ways to define stopping procedure. You can check literature.

Briefly

- EMD procedure decomposes a signal into residual and IMFs.
- Can be written as ($x(t)$ is signal, $imf_i(t)$ is IMF, and $r(t)$ is residual):

$$x(t) = \sum_{i=1}^n imf_i(t) + r(t).$$

Modified image: Chaos by khteWisconsin, Flickr: <https://www.flickr.com/photos/9600117@N03/4296600404/>



Let's see some code!

- In case you even wondered... there is an “emd” package in R.
 - Donghoh Kim and Hee-Seok Oh (2009) EMD: A Package for Empirical Mode Decomposition and Hilbert Spectrum. *The R Journal*, 1, 40-46.
 - Donghoh Kim, Kyungmee O Kim and Hee-Seok Oh (2012a) Extending the Scope of Empirical Mode Decomposition using Smoothing. *EURASIP Journal on Advances in Signal Processing*, 2012:168.
 - Donghoh Kim, Minjeong Park and Hee-Seok Oh (2012b) Bidimensional Statistical Empirical Mode Decomposition. *IEEE Signal Processing Letters*, 19, 191-194.
 - Donghoh Kim and Hee-Seok Oh (2014) EMD: Empirical Mode Decomposition and Hilbert Spectral Analysis. R package version 1.5.7.
- If you prefer, it's not that hard to implement it by yourself.
- We can apply it for synthetic signals first!


```

library(EMD)

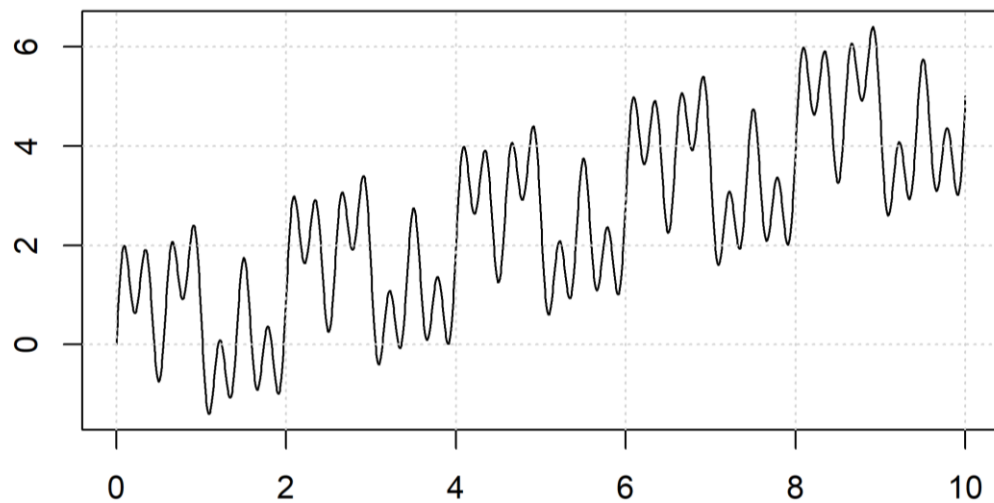
# sum of sines
N <- 1000
t <- seq(0, 10, length = N)
x <- sin(pi*t) + sin(3*pi*t) + sin(7*pi*t) + 0.5*t
rez <- emd(x, t, boundary = "wave")

# plots
png('signal.png', units='in', width=6, height=4, res=400)
plot(t, x, main = "signal",
     type = "l")
grid()
dev.off()

png('resultEMD.png', units='in', width=6, height=4, res=400)
par(mfrow = c(rez$nimf+1, 1), mar = c(2,1,2,1)) # margins (eng.)
rangeimf <- range(rez$imf)
for(ind in 1:rez$nimf) {
  plot(vreme, rez$imf[, ind], type="l",
       xlab = "", ylab = "", ylim = rangeimf,
       main = paste(ind, ". IMF", sep = "")); abline(h = 0)
}
plot(vreme, rez$residue, xlab = "",
     ylab = "", main = "rezidual", type = "l",
     axes = FALSE); box()
dev.off()

```

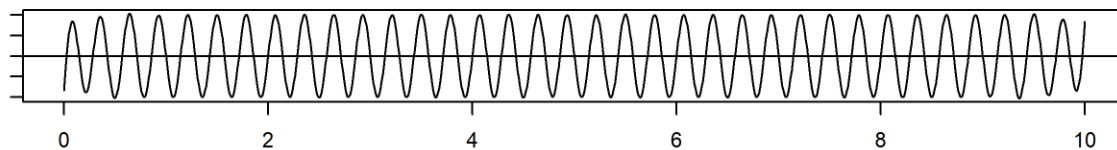
Signal



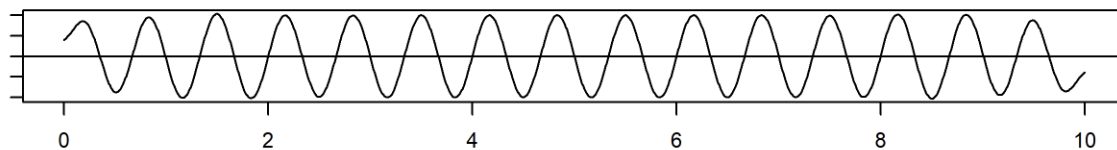
input



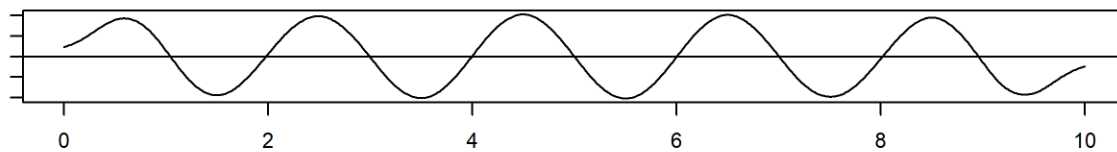
1. IMF



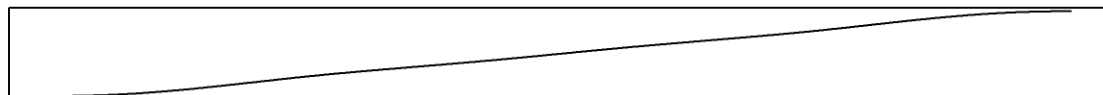
2. IMF



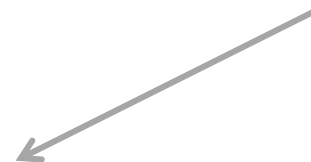
3. IMF



rezidual



output



Let's apply it to EMG+ECG

```
# EMD for EMG signals from Pectoralis major
dat <- read.table("EMG.txt")
head(dat)
emg <- dat$V1[1:8001]
fs <- 1000
vr <- seq(0, length(emg)/fs - 1/fs, by = 1/fs)
dev.off()

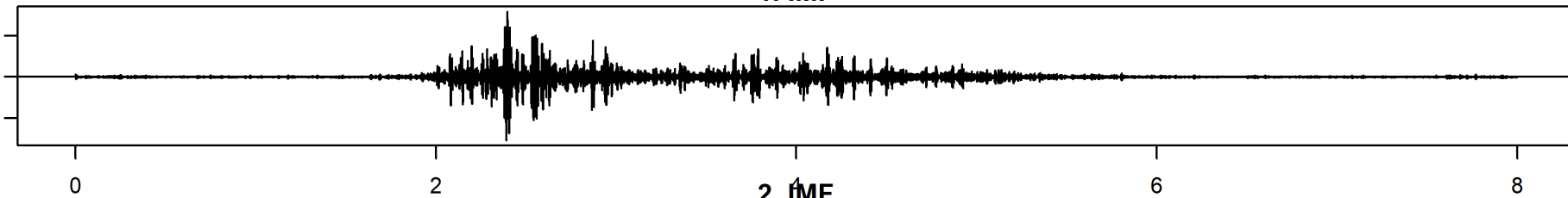
png('EMG.png', units='in', width=6, height=4, res=400)
plot(vr, emg, type = "l",
     main = "EMG signal (Pectoralis muscle)",
     xlab = "time [s]", ylab = "amplitude [mV]")
grid()
dev.off()

rez2 <- emd(emg, vr, boundary = "wave")

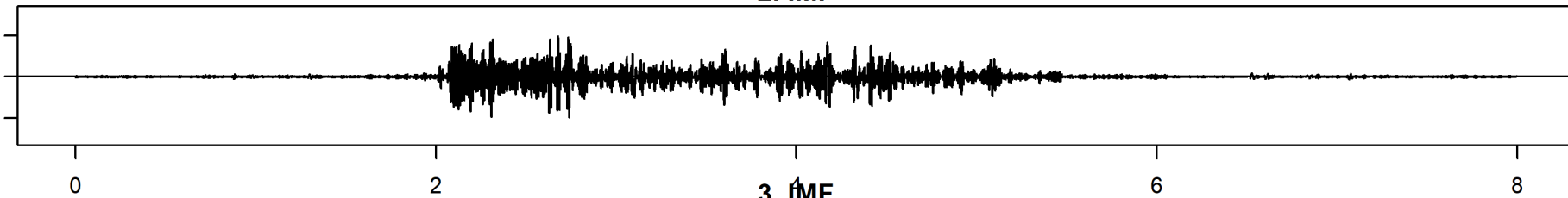
png('EMGEMD.png', units='in', width=8, height=6, res=400)
par(mfrow = c(rez2$nimf+1, 1), mar = c(1.2,1.2,1.2,1.2))
rangeimf <- range(rez2$imf)
for(ind in 1:rez2$nimf) {
  plot(vr, rez2$imf[, ind], type="l",
       xlab = "", ylab = "", ylim = rangeimf,
       main = paste(ind, ". IMF", sep = "")); abline(h = 0)
}
plot(vr, rez2$residue, xlab = "",
     ylab = "", main = "residual", type = "l",
     axes = FALSE); box()
dev.off()
```

This method is partly modified from TOBS course: <http://automatika.etf.bg.ac.rs/sr/13m051tobs>.

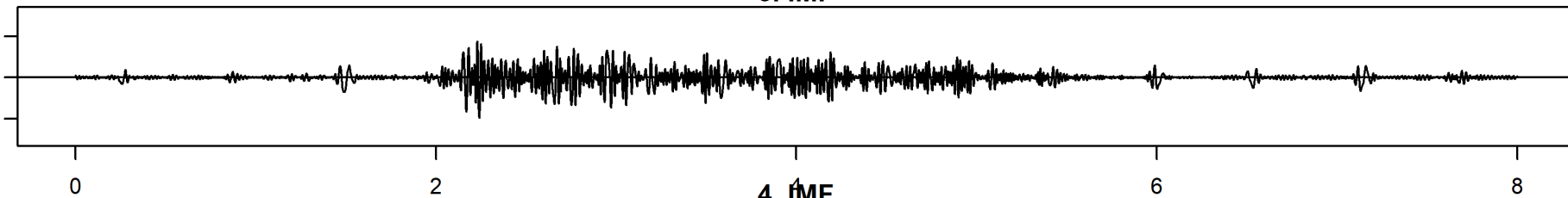
1. IMF



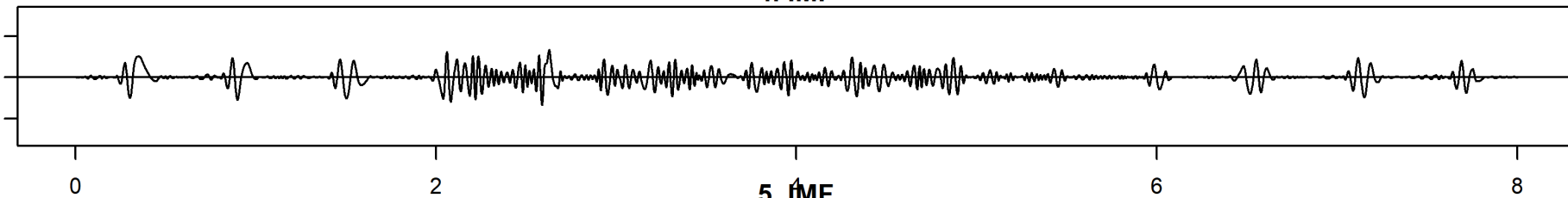
2. IMF



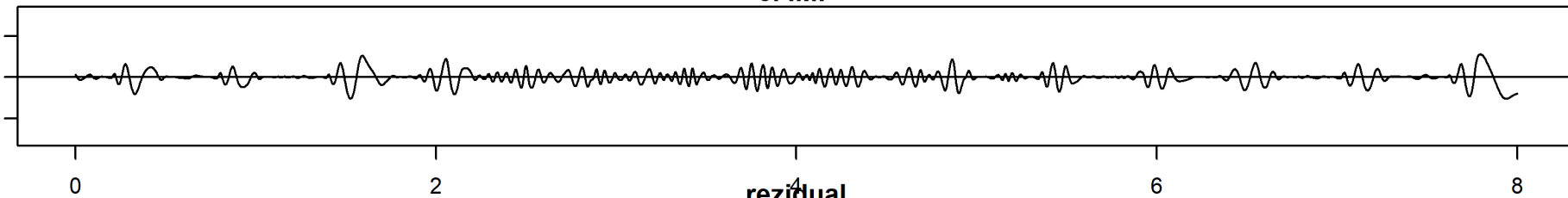
3. IMF



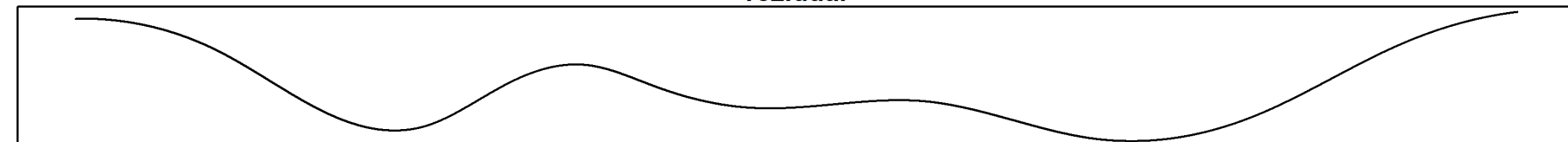
4. IMF

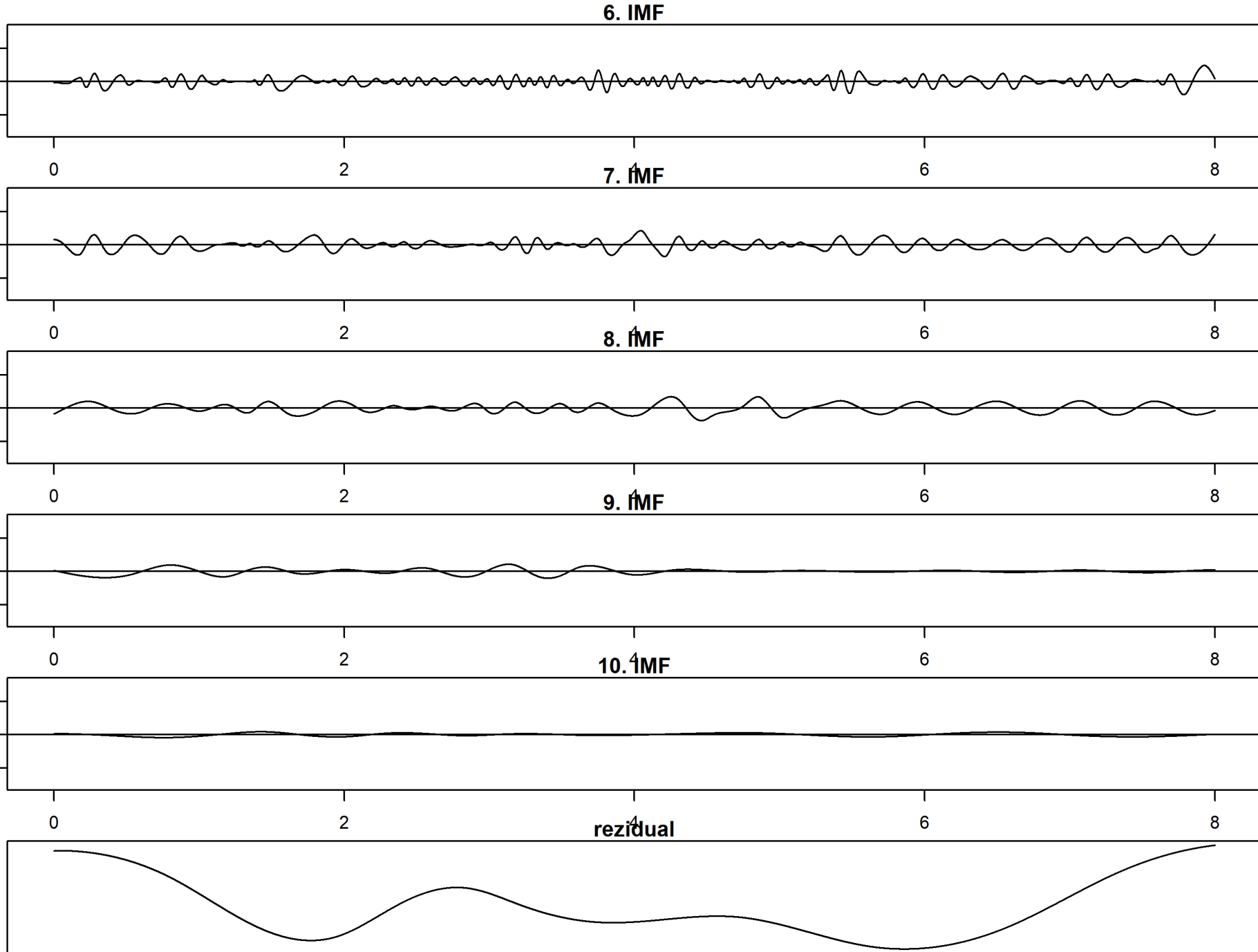


5. IMF



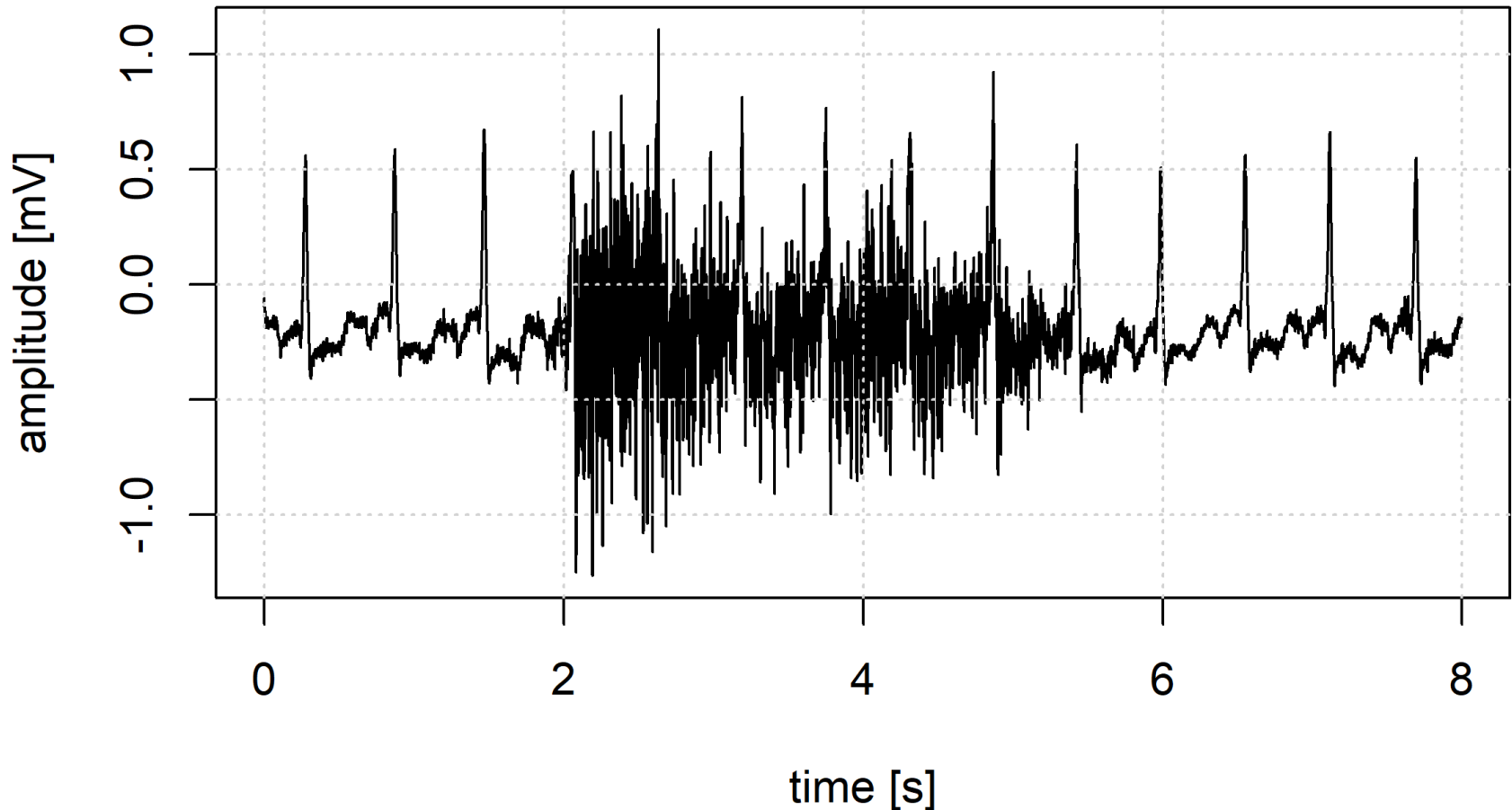
residual





What is “signal” and where is “noise”?

EMG signal (Pectoralis muscle)



Pros and cons of EMD

- PROS
 - It works well
 - It's intuitive
 - Can be used with non-stationary and non-linear time-series.
 - Can be used by beginners and non-professionals.
- CONS
 - Strong theoretical foundations are missing.
 - Can't solve all your problems!

Image: Morning - Bologna – Italy by [Lorenzoclick](https://www.flickr.com/photos/lorenzoclick/45050602391/), Flickr:
<https://www.flickr.com/photos/lorenzoclick/45050602391/>





Thinkinator

MACHINES & PEOPLE LEARNING

Less-tech version

More-tech version

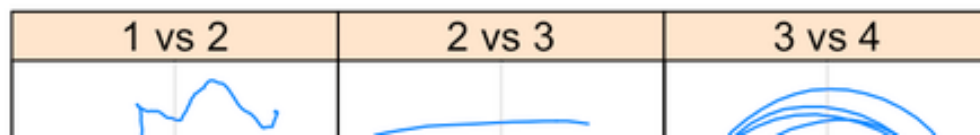
Everything

Where's the Magic? (EMD and SSA in R)

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When I first heard of SSA ([Singular Spectrum Analysis](#)) and the EMD ([Empirical Mode Decomposition](#)) I thought surely I've found a couple of magical methods for decomposing a time series into component parts (trend, various seasonalities, various cycles, noise). And joy of joys, it turns out that each of these methods is implemented in R packages: [Rssa](#) and [EMD](#).

In this posting, I'm going to document some of my explorations of the two methods, to hopefully paint a more realistic picture of what the packages and the methods can actually do. (At least in the hands of a non-expert such as myself.)





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