Use R!

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Sound Analysis and Synthesis with R

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Un livre sans histoires ni paroles
mais écrit avec passion pour

Chloé
Julia
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Preface

Sound is virtually always around us, everywhere, all the time. This morning, my day started on a rather unpleasant one: that of the repeated buzzing of my alarm clock. The night had been quiet despite the purr of the central heating, some motorbikes racing down the street, and blackbirds singing in one of our garden's trees at dawn. Now that I go down to the kitchen I can hear my clothes rub against my body and the wooden steps crack under my feet. As soon as I move, I realize that I myself generate sound. Quickly the house wakes up in an explosion of surrounding sounds seeping from the flush, the kettle, the toaster, the fridge, ventilation, and other domestic appliances. Music plays on the radio, but it does not cover the call of a hungry cat and family voices that soon invest and dominate in the acoustic space. My working day is a long, and sometimes exhausting, suite of sounds: metallic train screeches, mobile phone ringtones, office babbles, siren blares, street work roar, and radio tunes but also some amazing tropical sounds I recorded in a remote forest that I play back on my computer to escape that city soundscape. Sound is ubiquitous. It constantly reaches my body, being absorbed or bounced back, received and processed through my ears. But my body is also a sound source. My heart, my blood, my breath, my bones, and my vocal chords generate sound. I am sound in a world of sounds. No air, no life, no sound.

The soundscape I go through any given workday is mainly a city soundscape with very little enjoyable sound. Most of this sound can be considered as noise, which is actually sound conveying no information or overlapping other meaningful sounds. Nice soundscapes are certainly to be found in nature, in the middle of a dark forest or in the depth of an even darker ocean. Wildlife sound can be a bird song, a frog call, an insect hummer, a deer grunting, the exploding sound of a small pistol shrimp, or the amazing whistle of a giant whale. We often refer to the extraordinary diversity of life forms and colours, but life diversity is also to be found in animal vocalizations. Animals can produce rhythmic or continuous, pure-tone or polyphonic, harmonic or dysharmornic, synchronized or cacophonic sounds. Animals can almost play any instrument in any orchestra. Whatever their properties, the sounds emanating from animals are never exactly the same from one song bout to another one, from one individual to another one, and from one species to another one. The variety of animal

sound is so high that audio robots that can identify and interpret a human voice and chat with you on the phone can hardly discriminate the sound of a dolphin from a whale's. This animal acoustic diversity may be a challenge for sound analysis and synthesis, but more importantly, they are a living treasure that has to be enjoyed and preserved.

Animal sound variety is the matter of bioacoustics and ecoacoustics, two closely related life sciences disciplines. As a bioacoustician or ecoacoustician I often have to face the naive but essential question about my research: "Come on, Jérôme, what's your job all about? Is there really a point in listening to cicadas?". Addressing this question is almost the same issue as wondering why we need to name insects and flowers, scrutinize the sky to discover new stars, analyse the old century playwrights style, or understand the physics of a golf ball. Such fundamental research participates in the world's knowledge and bioacoustics. Ecoacoustics are no exception. It is essential to describe and to understand the patterns and processing that determine natural acoustic environments. To me, it is as important a thing to know how a pigeon call is produced as it is to know how a financial index is computed. However, it would be unfair to say that bioacoustics and ecoacoustics have no application in our daily lives. Next time you fly, think that the engines of the plane you are comfortably seated in will not fail after sucking up flying birds owing to the loudspeakers at the end of the runway that play specific alarm sounds and scare them away. These specific sounds were designed by Thierry Aubin, a renowned bioacoustician.

One of the most important soundmark of my city working day is the subtle noise of my fingers on the computer keyboard. As soon as I have settled administration, teaching, curation, and supervision duties I open `R` and play with. But why does `R` has such an important role in my professional life?

I have been reluctant to programming for ages. As a schoolboy and later as a university student I always disliked programming courses as I was confused with FOR, WHILE, IF, THEN, DO, and other mysterious instructions. I surely have always been a software user for work, but I never thought that one day, I would have written a command rather than just clicked on a mouse. It actually took me a long time to get into R and, eventually, to love `R`. I was introduced to `R` by a colleague of mine, Michel Baylac, who is an expert in morphometrics. This was at a morning lab coffee break and here follows the discussion we had some ten years ago. Consider that the original dialogue was in French:

Jérôme: Michel, how did you do your elliptic Fourier analysis in your last paper? I could not find any statistical software that does it.

Michel: I used `R`.

Jérôme: Sorry?

Michel: I programmed the EFA with `R`.

Jérôme: Air? I do not know this software. What is it?

Michel: Well it is a programming language deriving from `S`.

Jérôme: Ace? I do not know that one either. So you can do your own analysis. Sounds great!

Michel: It is. And it is free. No licence to purchase.

A few coffee breaks and some explanations about software names later, I successfully installed `R` and got started with it but I quickly gave up so used I was to graphical user interface. Fortunately, Michel gave an `R`-based statistics Master course a few weeks later so I went back to school and followed his instructions to run `R` multivariate analysis. But I had no data to analyse at that time and a few months later I had forgotten almost everything. A year after, I joined my future wife Caroline Simonis, who is a co-author of `seewave`, for a second session of Michel's course and I joined her again for a course on linear models with `R` organized by Emmanuel Paradis, who wrote the best-seller *`R` for beginners* and the wonderful phylogenetics `ape` package. I was probably more motivated to be with Caroline than to learn `R`, but Caroline understood the interest of `R` much faster than I did and she talked me into starting to write more code rather than simply `lm(y~x)`. This time I had data to look into at hand and free time to play with `R`. I can still remember that winter evening when I could plot my very first pure-tone spectrogram. The image was incomplete and inaccurate, but to me it was a wonderful and shiny plot that motivated me to keep on with `R`. I was so amazed at being able to run such an analysis by myself knowing all the production steps perfectly that in the following weeks I could not stop writing basic sound-analysis dedicated functions. I was lucky to be greatly helped by Caroline and also by Thierry Aubin, my mentor in bioacoustics and the author of the Syntana sofware that inspired the main `seewave` functions.

`R` definitely changed my research. I was no more limited to the utilities provided by prohibitive closed source softwares that my department could not afford. I could do almost everything by myself: I could draw fieldwork observation maps, read, analyse, and change my sound samples. I could collect qualitative and quantitative data, run batch processes, apply multivariate analysis, plot high-quality graphics, and eventually produce a paper combining `R` and LaTeX in a nice layout. The most important thing was that I was not only a user but also a designer. I was able to create, imagine, and share new tools with others.

I'm telling this very personal story as I think this could be the future of anyone who is a bit afraid of software programming. Learning `R` is not that difficult with a little help—which a nice woman like Caroline can do but this is not absolutely necessary. Just keep in mind that it is worth an effort and that the reward will be tremendous.

This book was written for students who are interested in bioacoustics and ecoacoustics, but I really hope that it can help anyone who is willing to dive into

the fantastic area of acoustics and into the endless land of R. A book and a cake are not that different: they both require time and energy to be made, but they are consumed apace. I really hope this book has a nice taste, and I wish you very nice reading and programming nights!

Paris, France Jérôme Sueur

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The core of this book is the `seewave` package which was initiated with Thierry Aubin and Caroline Simonis. `seewave` has been growing up during the last 11 years thanks to the contribution of Ethan C. Brown, Marion Depraetere, Camille Desjonquères, François Fabianek, Amandine Gasc, Eric Kasten, Stefanie LaZerte, Laurent Lellouch, Jonathan Lees, Jean Marchal, Sandrine Pavoine, David Pinaud, Alicia Stotz, Luis J. Villanueva-Rivera, Zev Ross, Carl G. Witthoft, and Hristo Zhivomirov. `seewave` and related analyses have been improving thanks to ideas, comments, checks, or bug reports by Andrey Anikin, Charlotte Curé, Stéphane Dray, Denis Dupeyron, Almo Farina, Arnold Fertin, Kurt Hornik, Emiliano A. Laca, Nadia Pieretti, Daniel Ridley-Ellis, Jesse Ross, Pavel Senin, and Arvind Sowmyan. `seewave` has been maintained on CRAN thanks to the crucial help of Kurt Hornik, Uwe Ligges, Brian Ripley, and Simon Urbanek, all members of the `R` core team.

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Contents

Acronyms

A	Maximum amplitude
AM	Amplitude modulation
DC	Direct current voltage
DFT	Discrete Fourier transform
E	Energy (J)
F	Force (N)
FFT	Fast Fourier transform
FM	Frequency modulation (Hz)
FT	Fourier transform
I	Intensity ($\mathrm{W\,m^{-2}}$)
IDFT	Inverse discrete Fourier transform
IFT	Inverse Fourier transform
ISTDFT	Inverse discrete short-time Fourier transform
ISTFT	Inverse short-time Fourier transform
P	Power (W)
Q	Quality factor
RMS	Root-mean-square
S	Area ($\mathrm{m^2}$)
SIL	Sound intensity level (dB)
SPL	Sound pressure level (dB)
STDFT	Short-time discrete Fourier transform
STFT	Short-time Fourier transform
SVL	Sound velocity level (dB)
T	Period (s)
TKEO	Teager-Kaiser energy operator
Z	Acoustic impedance ($\mathrm{N\,s\,m^{-3}}$)
ZCR	Zero crossing rate
a	Instantaneous amplitude
a	Acceleration ($\mathrm{m\,s^{-2}}$)
c	Sound celerity ($\mathrm{m\,s^{-1}}$)
d	Duration (s)

f	Ordinary frequency (Hz)
f_c	Carrier frequency (Hz)
f_d	Dominant frequency (Hz)
f_r	Resonant frequency (Hz)
f_s	Sampling frequency (Hz)
f_N	Nyquist frequency (Hz)
p	Pressure (Pa)
p_0	Reference air pressure at 0 s.l.m (1.1013×10^5 Pa)
p_{ref}	Human auditory threshold in air (2×10^{-5} Pa $= 20\,\mu$Pa $= 0$ dB)
v	Particle velocity ($\text{m}\,\text{s}^{-1}$)
t	Time (s)
ω	Angular frequency (rad)
λ	Wavelength (m)
ρ	Volumetric mass density ($\text{kg}\,\text{m}^{-3}$)
φ	Angular phase (rad)

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