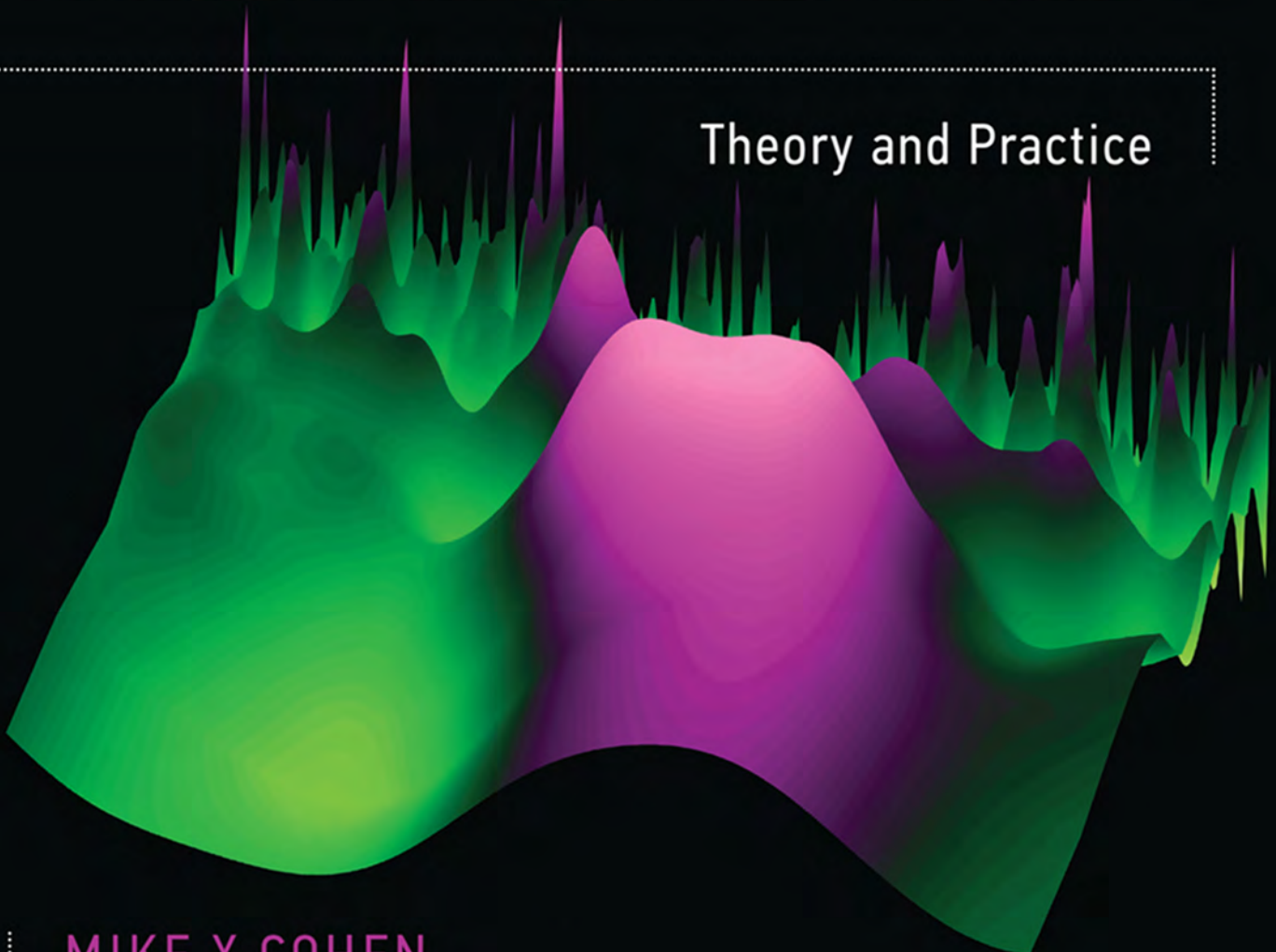


# ANALYZING NEURAL TIME SERIES DATA

Theory and Practice



MIKE X COHEN

## Analyzing Neural Time Series Data

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Mike X Cohen

# Analyzing Neural Time Series Data

Theory and Practice

Mike X Cohen

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## Preface

I began learning about time-frequency decomposition of EEG data in January of 2007, after a memorable end to a New Year's party led to a particular 30-day resolution. Before then, I knew the basics of interpreting time-frequency power plots from reading publications and online tutorials, but it was mostly magic to me; I had no idea *how* those red and blue blobs came to be and what they really meant. With the extra time on my hands, I decided to learn how to create a time-frequency power plot. I wanted to understand how the data went from wiggly lines to colorful two-dimensional (2-D) plots. It was hard in the beginning—I thought, for example, that a Morlet wavelet was some kind of breakfast dish—but after some trial and error, I managed to work out how to construct a wavelet in Matlab, how to perform convolution using the Matlab `conv` function (although I didn't really understand what convolution was), how to compute a decibel, and so on. And it worked! I turned a wiggly line into a colorful 2-D time-frequency power plot.

I initially thought that I would be satisfied with that bit of knowledge and that I would go back to my ERP and fMRI studies. I was wrong. Perhaps there was some afterburn of my New Year's resolution, or perhaps some piece of sanity inside me withered away, but I couldn't stop there. I was unsatisfied with what I knew about time-frequency-based analyses of EEG data, and I had to learn more. Even as I finish writing this book—exactly 6 years after making that fateful New Year's resolution (I am writing this on December 31, 2012)—I remain unsatisfied with what I know about time-frequency-based analyses of EEG data. What started off as a means to satisfy an idle curiosity and pass a few hours in the evenings turned into a career- and life-absorbing obsession that has not abated since early 2007. That obsession is to understand the mathematical and Matlab-implementation mechanics of EEG data analyses and to figure out ways to explain how those analyses work to people who are intelligent but who lack a PhD in mathematics (including myself, at least concerning the latter category).

I suspect that many people who apply time-frequency-based analyses are like me before 2007: they know the basics of how to interpret the colorful plots, but they also feel that some magic is involved, or at least, some very complicated math that they don't, won't, and can't understand. This is unfortunate for a number of reasons because, as I outline in chapters 1 and 37, learning the methods behind the magic will help scientists be better scientists.

Each year, I teach a class on analyzing EEG data in Matlab, and nearly every person in that class, ranging from advanced bachelor's students to full professors, starts off knowing very little about time-frequency-based analyses and, within 2 months, can program and talk intelligently about some of the most advanced analyses applied to EEG data. This is not due to any special quality of their teacher, but rather, it is because the material is not that difficult to learn; there is simply a lack of good resources from which to learn it.

The difficult part is explaining the math and theory in a language that nonmathematicians can understand. No offense to those with a PhD in mathematics or physics, but I think that the math experts who develop the analyses forget what it's like not to have their impressive amount of background knowledge. They forget what it's like not to know what convolution means or how a Fourier transform works, and they forget that to many people—even highly educated psychologists and neuroscientists—an imaginary number is something out of a trippy 1960s cartoon, and a complex space is a description of an M. C. Escher drawing. Thus, the overarching goal of this book is to demystify time-frequency-based analyses, to take the magic out of those red and blue blobs, and to try to make this wealth of powerful and insightful data analysis tools accessible to anyone with sufficient motivation and some spare time, regardless of their background in math, Matlab programming, or EEG research.

Writing this book was an incredibly rewarding experience for me, much more so than I initially thought it would be. I do not know whether it will be as good and accessible a resource as I intend it to be, but I hope that you find working through this book educational and rewarding. Good luck and have fun. And be careful what you wish for on New Year's Eve!

## Acknowledgments

Although I wrote all of the words and the Matlab code in this book on my own, this work is the culmination of many years of lessons learned from myriad experiences and from myriad people. I am and will continue to be shaped by the stimulating, encouraging, and, at times, disillusioning and frustrating interactions I have with colleagues, friends, mentors, and students, by lectures I have heard and symposia I have attended, and by the scientific papers and manuscripts I have read (even the ones that could and should have been better). I will not list names here because the list would be too long and the danger of accidentally omitting names is too great. If you ever had a discussion with me, if you ever gave a talk when I was in the audience, if you ever asked me a difficult question during one of my talks or poster presentations, if you ever reviewed one of my manuscripts or grant proposals, or if you ever wrote a paper that I read or reviewed: Thank you.