

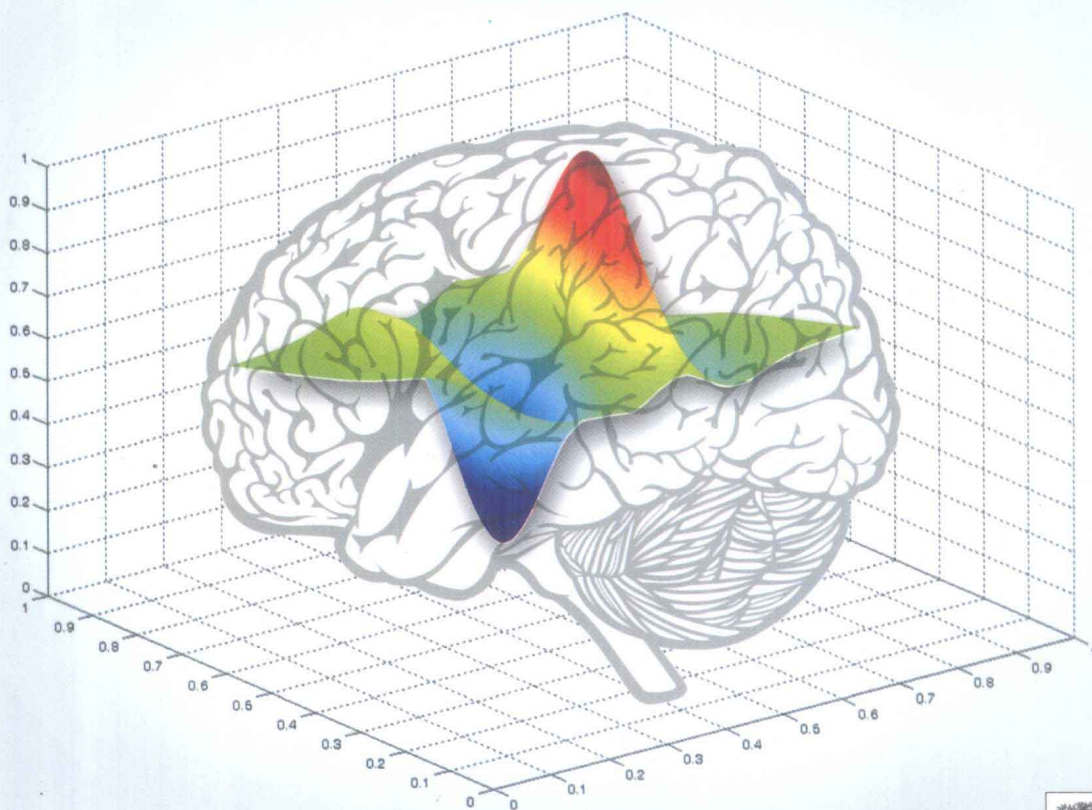
# MATLAB<sup>®</sup> for Neuroscientists

An Introduction to Scientific Computing in MATLAB<sup>®</sup>

# 神经科学MATLAB<sup>®</sup>教程

## MATLAB<sup>®</sup>科学计算导论

Pascal Wallisch, Michael Lusignan, Marc Benayoun  
Tanya I. Baker, Adam Seth Dickey and Nicholas G. Hatsopoulos



神经科学研究与进展  
**MATLAB<sup>®</sup> for Neuroscientists**  
An Introduction to Scientific Computing in MATLAB<sup>®</sup>

# 神经科学 MATLAB<sup>®</sup> 教程

MATLAB<sup>®</sup> 科学计算导论

Pascal Wallisch, Michael Lusignan,  
Marc Benayoun, Tanya I. Baker, Adam Seth Dickey and  
Nicholas G. Hatsopoulos

科学出版社

北京

图字：01-2011-4372 号

This is an annotated version of

**MATLAB® for Neuroscientists: An Introduction to Scientific Computing in MATLAB®**

By Pascal Wallisch, Michael Lusignan, Marc Benayoun, Tanya I. Baker, Adam Seth Dickey and Nicholas G. Hatsopoulos.

Copyright © 2009 Elsevier Inc.

ISBN: 978-0-12-374551-4

All rights reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

AUTHORIZED EDITION FOR SALE IN P. R. CHINA ONLY

本版本只限于在中华人民共和国境内销售

#### 图书在版编目(CIP)数据

神经科学 MATLAB®教程：MATLAB®科学计算导论 = MATLAB® for Neuroscientists: An Introduction to Scientific Computing in MATLAB®; 英文 / (美) 瓦利施 (Wallisch, P.) 等编著. —北京：科学出版社，2012 (神经科学研究与进展)

ISBN 978-7-03-033056-7

I. ①神… II. ①瓦… III. ①神经科学-计算机辅助计算-软件包, Matlab-英文 IV. ①Q189-39

中国版本图书馆 CIP 数据核字 (2011) 第 263898 号

责任编辑：李小汀/责任印制：钱玉芬/封面设计：耕者设计工作室

科学出版社出版

北京东黄城根北街 16 号

邮政编码：100717

<http://www.sciencep.com>

双青印刷厂印刷

科学出版社发行 各地新华书店经销

\*

2012 年 1 月第 一 版 开本：787×1092 1/16

2012 年 1 月第一次印刷 印张：25 3/4

字数：610 000

定价：128.00 元

(如有印装质量问题，我社负责调换)

## 中文导读

Talk is cheap, show me the code.

——Linus Torvalds<sup>①</sup>

我们是如何看见这纷繁美丽的世界？公元前 5 世纪，古希腊哲学家恩培多克勒（Empedocles, ca. 490—430 BCE）认为万事万物是由火、气、水和土四种元素组成，而掌管爱与美的女神阿佛罗狄特点燃了眼睛中的火焰，发出光芒照射在外界上，于是我们便有了视觉。随后的哲学家柏拉图、欧几里得、托勒密等进一步完善了这个理论，提出了眼睛发出光线与阳光等外在光源发出的光线在物体上交汇而产生视觉，完美的解释了为什么我们在黑夜无法看见物体的原因。这个貌似自洽的理论主宰了后人对视觉的认识——直到现在，还有近 50% 的美国大学生相信我们是通过眼睛发出的光束而看到世界的（Winer et al., *American Psychologist*, 2002）。

然而，再完美的理论，也只是理论，而不是事实。理论只有经过实验的验证、数据的支持，才可能是事实。这个看似简单的科学逻辑，却并不是一开始就根植于学者的心中，因为直到这个理论被提出 1500 多年之后，才有人尝试用实验的方法来验证这个理论。他就是被尊称为第一个实验心理学家的伊本海萨姆（Ibn al-Haytham, 965—ca. 1039）。在他所著的《光学》一书中，他研究了眼睛的解剖结构，借助小孔成像的实验，用科学的数据阐明了视觉被动成像的机制，推翻了先哲们的理论。这是一个了不起的突破！从哲学思辨，从对先哲的追随，到开始用自己的眼和耳去观察这个世界，用实验和数据去验证先哲的理论，却不是一件容易的事情。伽利略在给开普勒的信（1597）中感叹到：“你该如何来描述这些所谓的有学识的精英？他们对经典充满顽固的信仰，而不愿意那怕是仅仅通过望远镜向外面未知的世界看上一眼。我们是应当嘲笑他们，还是应当为他们哭泣？”

今天，实验验证已经成为深入人心的基本原则。但是，我们似乎比前人更加迷惘。这是因为我们已经淹没在无穷无尽的数据海洋之中。当 Helmholtz（1821—1894）研究颜色视觉的时候，他手里只有分光仪和自己的直觉；而现在我们有了炫目的新技术。在基因层面上，通过分子遗传学技术，我们可以获得受试者的整个基因图谱，从而筛选出对视觉有特异调控功能的基因位点。在神经元层面，通过神经电生理技术，我们可以获得受试者视觉区域单个神经的神经发放脉冲和局部场电位；更重要的是，我们可以获得神经环路的信息，从而了解众多的神经元如何形成一个整体，对外部世界进行群体编码。在神经核团层面，通过功能磁共振脑成像技术、脑电图和脑磁图，我们可以获得视觉信息在全脑层面上的编码、流动和加工，从而将物理世界与心理世界一一映射、合二为一。在行为层面上，借助心理物理法，我们可以通过刺激输入和行为反应模式，构建

---

① 能说算不上什么，有本事把你的代码给我看看。

受试者加工视觉信息的认知模型。这些数据，分别从基因、神经元、神经核团、神经环路和行为等多个层面上描述了视觉的特性。现在的问题是：（1）如何从这些海量数据中，挖掘到关键的信息；（2）如何将这些信息整合起来，形成对视觉的一个完整的描述。

在传统的科学研究中，精巧的实验设计是放在第一位的。现在，随着各种海量数据的累积，更大的挑战来自于对数据本身的处理、挖掘和理解。例如，在人的大脑中，大约有一千亿个神经元，而每一个神经元平均和七千个神经元连接。如果我们把这些神经连接串联起来，其总长度可以达到上千万公里。因此，研究者现在面对的不是以前研究面对的反应时和正确率等只有几 K( $10^3$  位) 的数据，而是上 G( $10^9$  位) 甚至上 T( $10^{12}$  位) 的神经和基因数据；其次，新的分析方法也在层出不穷。以前我们是基于心理过程的线性假设，在数据分析中采用了减法原则，即用实验条件减去控制条件的一元方法；随后多元分析方法，如支持向量机等，使得我们更多从模式的角度来对数据分类和挖掘。在最近兴起的连接组学研究中，小世界网络等图论的方法也被引入进来。简而言之，海量的数据和复杂的算法迫使我们每一个研究者去寻找新的数据分析平台。

我从 1991 年接触计算机以来，使用过 SPSS, SAS 等多种统计软件，也用 C 语言等写过上万行的程序。但是直到 1999 年我在美国麻省理工学院 (MIT) 接触到 MATLAB, 我才真正开始享受数据处理的乐趣。在我现在的实验室里，我们用 MATLAB+Psychophysics Toolbox 编制实验程序；用 MATLAB+EEGLab 对脑电图和脑磁图的数据、MATLAB+Freesurfer/FSL 对磁共振数据进行分析；用 MATLAB+MVPA toolbox 进行更高阶的多元分析，MATLAB+Brain Connectivity Toolbox 进行复杂网络分析。于是一切人类智能的本质，便在 MATLAB 这个朴素的文本界面下，一一展现出来。

由 Wallisch 等人撰写的这本《神经科学 MATLAB® 教程》，是我见过众多有关 MATLAB 的教科书中最好的一本。它显然不能对缠绕着每一个研究者的每一个问题提供解决方案；但是它打开了一道门，这道门通向令人激动的未知世界。

刘嘉，博士  
认知神经科学与学习国家重点实验室  
北京师范大学

#### 导读作者简介：

刘嘉，男，国家基金委杰出青年基金获得者，中科院百人计划入选者，美国富布莱特研究学者奖金获得者。1995 年和 1997 年在北京大学心理学系分获学士和硕士学位、无线电系获辅修学位；2003 年在麻省理工学院脑与认知科学系获博士学位。现为北京师范大学认知神经科学与学习国家重点实验室副主任，北师大脑成像中心主任。

## 前 言

I hear and I forget.

I see and I remember.

I do and I understand.

——孔子<sup>①</sup>

本书的创作源于过去几年一系列定量神经科学的课程，特别是芝加哥大学的研究生计算神经科学课程。这个项目开始于2001年，是为数不多的集中关注计算神经科学并且包括了完整的细胞、系统、行为和认知神经科学、神经元模型的项目。这些课程很多既包括讲座又包括实验室研讨，从而让学生获得使用MATLAB软件来解决各种神经科学问题的亲身体验。

这本书的内容以将MATLAB作为一个综合性的平台，跨越整个实验神经科学循环——刺激产生、数据收集和实验控制、数据分析和数据建模这一哲学理念为导向。我们发现MATLAB这种方法的使用并不是那么普遍。相当多的实验室在刺激生成、数据收集、数据分析和数据建模上都分别使用不同的专业软件。尽管这是一个可行的选择，却会导致一些问题：即需要在不同的平台和格式上转换数据，保持更新和学习许多软件包，而且当你进入一个新的实验室，你必须去学习全新的专业自制“本地”软件。在科学家的职业生涯中，我们意识到，这些障碍并非微不足道的，而是决定效率的一个重大因素。

我们同时相信这种将MATLAB的应用“全面化”的策略对教育目标来说是有意义的，因为它允许使用者在单一的编程环境中逐步解决各种各样的计算问题和挑战。这为你巧妙简洁地解决问题有促进作用。我们的教学经验使我们可以不局限于将MATLAB作为一个计算机程序语言，而是将它当做一个解决神经科学问题的工具。此外，这也与我们现有的对学习过程的理解相吻合。重复运用数据会促使我们重新提取概念，通过这种方式反过来帮助我们学习（Karpicke & Roediger, 2008）。

这本书在结构上分为四个部分，每一个部分有几章。第一部分简要介绍了MATLAB软件中最常用的功能，以及MATLAB中的基本编程。已经熟悉MATLAB的用户可以跳过这一部分。这一部分的目的是带领大家对MATLAB环境的能力进行了解。这是最基础的一部分，只有掌握了这些内容才能进行下一步的学习。本书其他部分集中在如何将MATLAB作为解决神经科学中出现的问题的工具。第二部分内容是如何使用MATLAB来收集数据。为了使内容具有共性，章节内容关注于如何从人类被试上收集数据，然而用户还是可以很容易地将其推广到动物数据的采集上去。第三部分关注如何将MATLAB用于数据收集和制图。这部分内容是本书的核心内容，同时也是MAT-

---

<sup>①</sup> 本句应译自《荀子·儒效》：“不闻不若闻之，闻之不若见之，见之不若知之，知之不若行之。学至于行（之）而止矣”。

LAB 最常被使用的部分。我们特别探索了多种数据集的分析，包括电生理学和神经影像学的“真实”数据。第四部分着重介绍 MATLAB 程序的数据建模，并附录探讨了 MATLAB 的哲学和潜在的数学运算。在每个章节的开头都设有本章目标和对关心问题（神经科学或心理学）背景的一个简短介绍。接着介绍解决这个问题必须用到的 MATLAB 概念，我们将这些概念分解为多个小部分，并提供示例代码。我们邀请你们在一组练习中去修改、扩展和即兴发挥这些例子。最后，在每章的末尾都指定了一个项目，这个项目要求你们将学到的知识整合成一个连贯的整体。根据我们的经验，如果这本书是用于教学的话，我们相信这些章节可以作为一个自成一体的“实验”组件。

本质上，我们致力于编一本这样的书：当我们自己第一次学习 MATLAB 的时候，或是过去教学的时候，我们会希望手里有这本书。我们希望，这样的一本书就是你现在手中拿着的这本书。

如果没有大量朋友持续的支持，我们不可能完成这本书。首先，要感谢我们的家人的支持，感谢他们无限的耐心和不懈的鼓励。同时还要感谢我们的学生们为这项事业提供了初始推动力，并且为我们的原稿提供了持续的反馈。特别感谢 Steve Shevell，他建议我们将这个项目放在所有工作的第一位。此外我们要感谢所有 Elsevier 出版集团中参加这本书的产生和发展的工作人员，特别是各位编辑们，Johannes Menzel, Sarah Hajduk, Clare Caruana, Christie Jozwiak, Chuck Hutchinson, Megan Wickline 和 Meg Day，他们的智慧、专业和耐心确实使结果大大不同。意外的是有另一个 Meg 参与了该项目，即来自 MathWorks™ 图书计划的 Meg Vulliez。另外，我们想感谢帮忙制作插图的 Kori Lusignan 和 Amber Martell，在这个计划的早期阶段提供了建议和指导的 Wim van Drongelen。此外我们谢谢 Armen Kherlopian 和 Gopathy Purushothaman 对我们的工作提供宝贵的见解。我们也要感谢 Kristine Mosier 提供了我们在 FMRI 实验室使用的手指敲击任务的功能性磁共振成像数据，要感谢 Aaron Suminski 对这些数据的后期处理。最重要的是，我们感谢所有因为我们的疏忽而没有明确指出但却值得我们感谢的人。最后，我们想要谢谢你，读者，因为你愿意加入我们这个激动人心的旅程。我们真诚地希望可以帮你到达你理想的目的地。

(陈麒璇 刘 嘉 译)

# Preface

---

*I hear and I forget.*

*I see and I remember.*

*I do and I understand.*

Confucius

The creation of this book stems from a set of courses offered over the past several years in quantitative neuroscience, particularly within the graduate program in computational neuroscience at the University of Chicago. This program started in 2001 and is one of the few programs focused on computational neuroscience with a complete curriculum including courses in cellular, systems, behavioral, and cognitive neuroscience; neuronal modeling; and mathematical foundations in computational neuroscience. Many of these courses include not only lectures but also lab sessions in which students get hands-on experience using the MATLAB<sup>®</sup> software to solve various neuroscientific problems.

The content of our book is oriented along the philosophy of using MATLAB as a comprehensive platform that spans the entire cycle of experimental neuroscience: stimulus generation, data collection and experimental control, data analysis, and finally data modeling. We realize that this approach is not universally followed. Quite a number of labs use different—and

specialized—software for stimulus generation, data collection, data analysis, and data modeling, respectively. Although this alternative is a feasible strategy, it does introduce a number of problems: namely, the need to convert data between different platforms and formats and to keep up with a wide range of software packages as well as the need to learn ever-new specialized home-cooked “local” software when entering a new lab. As we have realized in our own professional life as scientists, these obstacles can be far from trivial and a significant detriment to productivity.

We also believe that our comprehensive MATLAB “strategy” makes particular sense for educational purposes, as it empowers users to progressively solve a wide variety of computational problems and challenges within a single programming environment. It has the added advantage of an elegant progression within the problem space. Our experience in teaching has led us to this approach that does not focus on the inherent structure of MATLAB as a computer programming language but rather as a tool



for solving problems within neuroscience. In addition, it is well founded in our current understanding of the learning process. Constant use of the information forces the repeated retrieval of the introduced concepts, which—in turn—facilitates learning (Karpicke & Roediger, 2008).

The book is structured in four parts, each with several chapters. The first part serves as a brief introduction to some of the most commonly used functions of the MATLAB software, as well as to basic programming in MATLAB. Users who are already familiar with MATLAB may skip it. It serves the important purpose of a friendly invitation to the power of the MATLAB environment. It is elementary insofar as it is necessary to have mastered the content within before progressing any further. Later parts focus on the use of MATLAB to solve computational problems in neuroscience. The second part focuses on MATLAB as a tool for the collection of data. For the sake of generality, we focus on the collection of data from human subjects in these chapters, although the user can easily adapt them for the collection of animal data as well. The third part focuses on MATLAB as a tool for data analysis and graphing. This part forms the core of the book, as this is also how MATLAB is most commonly used. In particular, we explore the analysis of a variety of datasets, including “real” data from electrophysiology as well as neuroimaging. The fourth part focuses on data modeling with MATLAB, and appendices address the philosophy of MATLAB as well as the underlying mathematics. Each chapter begins with the goals of the chapter and a brief background of the problem of interest (neuroscientific or psychological), followed by an introduction to the MATLAB concepts necessary to address the problem by breaking it down into smaller parts and providing sample code. You are invited to modify, expand, and improvise on these

examples in a set of exercises. Finally, a project is assigned at the end of the chapter which requires integrating the parts into a coherent whole. Based on our experience, we believe that these chapters can serve as self-contained “lab” components of a course if this book is used in the context of teaching.

In essence, we strived to write the book that we wished to have had when first learning MATLAB ourselves, as well as the book that we would have liked to have had when teaching MATLAB to our students in the past. Our hope is that this is the very book you are holding in your hands right now.

We could have not written this book without the continuous support of a large number of friends. First and foremost, we would like to thank our families for their kind support, their endless patience, as well as their untiring encouragement. We also would like to extend thanks to our students who provided the initial impetus for this undertaking as well as for providing constant feedback on previous versions of our manuscript. Steve Shevell deserves thanks for suggesting that the project is worth pursuing in the first place. In addition, we would like to thank everyone at Elsevier who was involved in the production and development of this book—in particular our various editors, Johannes Menzel, Sarah Hajduk, Clare Caruana, Christie Jozwiak, Chuck Hutchinson, Megan Wickline, and Meg Day—their resourcefulness, professionalism and patience really did make a big difference. Curiously, there was another Meg involved with this project, specifically Meg Vulliez from The MathWorks™ book program. In addition, we would like to thank Kori Lusignan and Amber Martell for help with illustrations and Wim van Drongelen for advice and guidance in the early stages of this project. Moreover, we thank Armen Kherlopian and Gopathy Purushothaman who were kind enough to provide us with valuable insights throughout

our undertaking. We also would like to thank Kristine Mosier for providing the finger-tapping functional magnetic imaging data that we used in the fMRI lab and would like to thank Aaron Suminski for his help in the post-processing of that data. Importantly, we thank everyone whom we neglected to name

explicitly but deserves our praise. Finally, we would like to thank you, the reader, for your willingness to join us on this exciting journey. We sincerely hope that we can help you reach your desired destination.

*The authors*

# How to Use This Book

---

A text of a technical nature tends to be more readily understood if its design principles are clear from the very outset. This is also the case with this book. Hence, we will use this space to briefly discuss what we had in mind when writing the chapters. Hopefully, this will improve usability and allows you to get most out of the book.

## STRUCTURAL AND CONCEPTUAL CONSIDERATIONS

A chapter typically begins with a concise overview of what material will be covered. Moreover, we usually put the chapter in the broader context of practical applications. This brief introduction is followed by a discussion of the conceptual and theoretical background of the topic in question. The heart of each chapter is a larger section in which we introduce relevant MATLAB<sup>®</sup> functions that allow you to implement methods or solve problems that tend to come up in the context of the chapter topic. This part of the chapter is enriched by small exercises and suggestions for exploration. We believe that doing the exercises is imperative to attain a sufficiently deep understanding of the function in question, while the suggestions for exploration are aimed at readers who are particularly interested in broadening their understanding of a given function. In this spirit, the exercises are usually rather

specific, while the suggestions for exploration tend to be of a rather sweeping nature. This process of successive introduction and reinforcement of functions and concepts culminates in a “project”, a large programming task that ties all the material covered in the book together. This will allow you to put the learned materials to immediate use in a larger goal, often utilizing “real” experimental data. Finally, we list the MATLAB functions introduced in the chapter at the very end. It almost goes without saying that you will get the most out of this book if you have a version of MATLAB open and running while going through the chapters. That way, you can just try out the functions we introduce, try out new code, etc.

Hence, we implicitly assumed this to be the case when writing the book.

Moreover, we made sure that all the code works when running the latest version of MATLAB (currently 7.7). Don’t let this concern you too much, though. The vast majority of code should work if you use anything above version 6.0. We did highlight some important changes where appropriate.

## LAYOUT AND STYLE

The reader can utilize not only the conceptual structure of each chapter as outlined above, but also profit from the fact that we systematically encoded information about the function of different text parts in the layout and style of the book.

The main text is set in 10/12 Palatino-Roman. In contrast, executable code is **bolded** and offset by >>, such as this:

```
>> figure  
>> subplot(2,2,1)  
>> image(test_disp)
```

The idea is to type this text (without the >>) directly into MATLAB. Moreover, functions that are first introduced at this point are **bolded** in the text. Exercises and Suggestions for exploration are set in italics and separated from the main text by boxes.

Equations are set in 10/12 Palatino-Roman. Sample solutions in 10/12 Palatino-Bold.

## COMPANION WEBSITE

The successful completion of many chapters of this book depends on additional material (experimental data, sample solutions and other supplementary information) which is accessible from the website that accompanies this book. For example, a database of executable code will be maintained as long as the book is in print. For information on how to access this online repository, please see page ii.

# About the Authors

---

**Pascal Wallisch, PhD, Center for Neural Science, New York University**

Pascal received his PhD from the University of Chicago and is now a postdoctoral fellow at New York University. He is currently studying the processing of visual motion. Pascal is passionate about teaching, as well as the communication of scientific concepts to a wider audience. He was recognized for his distinguished teaching record by the University of Chicago Booth Prize.

**Michael Lusignan, Committee on Computational Neuroscience, University of Chicago**

Michael is an advanced graduate student who has enjoyed teaching several courses involving MATLAB to graduate, as well as undergraduate students. He infuses his teaching with eight years of experience in active software development. His current interests include sensory encoding in neuroethological model systems.

**Marc Benayoun, Committee on Computational Neuroscience, University of Chicago**

Marc is an MD/PhD student currently interested in applying statistical field theory to study neural networks with applications to epilepsy. He has an extensive teaching record and was also awarded the University of Chicago Booth Prize.

**Tanya I. Baker, PhD, Junior Research Fellow, Crick-Jacobs Center for Theoretical Neurobiology, The Salk Institute for Biological Studies, La Jolla, California**

Tanya is a junior research fellow modelling large-scale neuronal population dynamics using modern statistical methods. Previously, she was a post-doctoral lecturer at the University of Chicago where she developed and taught *Mathematical Methods for the Biological Sciences*, a new year-long course with a computer lab component. She received her PhD in Physics at the University of Chicago and her BS in Physics and Applied Mathematics at UCLA.

**Adam Dickey, Committee on Computational Neuroscience, University of Chicago**

Adam is an MD/PhD candidate at the University of Chicago. He is currently a graduate student in the laboratory of Dr. Nicholas Hatsopoulos. Adam is interested in improving decoding techniques used for neural prosthetic control.

**Nicholas G. Hatsopoulos, PhD, Department of Organismal Biology and Anatomy & Department of Neurology, University of Chicago**

Nicholas is Associate Professor and Chairman of the graduate program on Computational Neuroscience. He teaches a course in

Cognitive Neuroscience which formed the basis for some of the chapters in the book. His research focuses on how ensembles of cortical neurons work together to control, coordinate, and learn complex movements

of the arm and hand. He is also developing brain-machine interfaces by which patients with severe motor disabilities could activate large groups of neurons to control external devices.

# 目 录

前言 .....	vii
作者简介 .....	xi
如何使用本书 .....	xiii
第一部分 基本原理	
1 入门 .....	3
2 MATLAB 指南 .....	7
第二部分 MATLAB 数据收集	
3 视觉搜索和突显 .....	59
4 注意 .....	71
5 心理物理学 .....	79
6 信号检测论 .....	97
第三部分 MATLAB 数据分析	
7 时频分析 (I): 傅里叶变换 .....	117
8 时频分析 (II): 非平稳信号和谱图 .....	125
9 小波分析 .....	133
10 卷积 .....	141
11 相位平面分析 .....	153
12 Fitzhugh-Nagumo 模型 .....	163
13 神经数据分析: 编码 .....	173
14 主成分分析 .....	183
15 信息理论 .....	193
16 神经信息解码 (I): 离散变量 .....	203
17 神经信息解码 (II): 连续变量 .....	211
18 功能磁共振成像 .....	219
第四部分 MATLAB 数据建模	
19 电压门控通道 .....	229
20 单神经元模型 .....	239
21 视网膜模型 .....	247
22 脉冲神经元的简化模型 .....	255

23 Fitzhugh-Nagumo 模型：行波 .....	261
24 决策理论.....	275
25 Markov 模型 .....	283
26 泊松过程描述电发放事件.....	291
27 突触传递.....	299
28 神经网络模型 (I)：有监督学习 .....	307
29 神经网络模型 (II)：无监督学习 .....	319
<b>附录 A：有关 MATLAB 的一些思考 .....</b>	<b>339</b>
<b>附录 B：线性代数回顾 .....</b>	<b>345</b>
<b>附录 C：主要方程列表 .....</b>	<b>355</b>
<b>参考文献.....</b>	<b>371</b>
<b>索引.....</b>	<b>379</b>

(陈麒璇 刘 嘉 译)



# Contents

---

**Preface** vii  
**About the Authors** xi  
**How to Use this Book** xiii

## Part I

---

### FUNDAMENTALS

1. Introduction 3  
2. MATLAB Tutorial 7

## Part II

---

### DATA COLLECTION WITH MATLAB

3. Visual Search and Pop Out 59  
4. Attention 71  
5. Psychophysics 79  
6. Signal Detection Theory 97

## Part III

---

### DATA ANALYSIS WITH MATLAB

7. Frequency Analysis Part I: Fourier  
Decomposition 117  
8. Frequency Analysis Part II: Nonstationary Signals  
and Spectrograms 125  
9. Wavelets 133  
10. Convolution 141  
11. Introduction to Phase Plane Analysis 153

12. Exploring the Fitzhugh-Nagumo Model 163  
13. Neural Data Analysis: Encoding 173  
14. Principal Components Analysis 183  
15. Information Theory 193  
16. Neural Decoding Part I: Discrete Variables 203  
17. Neural Decoding Part II: Continuous  
Variables 211  
18. Functional Magnetic Imaging 219

## Part IV

---

### DATA MODELING WITH MATLAB

19. Voltage-Gated Ion Channels 229  
20. Models of a Single Neuron 239  
21. Models of the Retina 247  
22. Simplified Model of Spiking Neurons 255  
23. Fitzhugh-Nagumo Model: Traveling Waves 261  
24. Decision Theory 275  
25. Markov Models 283  
26. Modeling Spike Trains as a Poisson Process 291  
27. Synaptic Transmission 299  
28. Neural Networks Part I: Unsupervised  
Learning 307  
29. Neural Network Part II: Supervised  
Learning 319

**Appendix A: Thinking in MATLAB** 339

**Appendix B: Linear Algebra Review** 345

**Appendix C: Master Equation List** 355

**References** 371

**Index** 379