Preface

The idea of writing this book entitled "Cognitive Networked Sensing and Big Data" started with the plan to write a briefing book on wireless distributed computing and cognitive sensing. During our research on large-scale cognitive radio network (and its experimental testbed), we realized that big data played a central role. As a result, the book project reflects this paradigm shift. In the context, sensing roughly is equivalent to "measurement."

We attempt to answer the following basic questions. How do we sense the radio environment using a large-scale network? What is unique to cognitive radio? What do we do with the big data? How does the sample size affect the sensing accuracy?

To address these questions, we are naturally led to ask ourselves: What mathematical tools are required? What are the state-of-the-art for the analytical tools? How these tools are used?

Our prerequisite is the graduate-level course on random variables and processes. Some familiarity with wireless communication and signal processing is useful. This book is complementary with our previous book entitled "Cognitive Radio Communications and Networking: Principles and Practice" (John Wiley and Sons 2012). This book is also complementary with another book of the first author "Introduction to Smart Grid" (John Wiley and Sons 2014). This current book can be viewed as the mathematical tools for the two Wiley books.

Chapter 1 provides the necessary background to support the rest of the book. No attempt has been made to make this book really self-contained. The book will survey many latest results in the literature. We often include preliminary tools from publications. These preliminary tools may be still too difficult for many of the audience. Roughly, our prerequisite is the graduate-level course on random variables and processes.

Chapters 2–5 (Part I) are the core of this book. The contents of these chapters should be new to most graduate students in electrical and computer engineering.

Chapter 2 deals with the sum of matrix-valued random variables. One basic question is "how does the sample size affect the accuracy." The basic building block of the data is the sample covariance matrix, which is a random matrix. Bernstein-type concentration inequalities are of special interest.

Chapter 3 collects together the deepest mathematical theorems in this book. This chapter is really the departure point of this whole book. Chapter 2 is put before this chapter since we want the audience to understand how to deal with the basic linear functions of matrices. The theory of concentration inequality tries to answer the following question: Given a random vector $\mathbf{x}$ taking value in some measurable space $\mathcal{X}$ (which is usually some high dimensional Euclidean space), and a measurable map $f : \mathcal{X} \to \mathbb{R}$, what is a good explicit bound on $\mathbb{P}\left(|f\left(\mathbf{x}\right) - \mathbb{E}f\left(\mathbf{x}\right)| \geqslant t\right)$? Exact evaluation or accurate approximation is, of course, the **central** purpose of probability theory itself. In situations where exact evaluation or accurate approximation is not possible, which is the case for many practical problems, concentration inequalities aim to do the **next best job** by providing rapidly decaying tail bounds. It is our goal of this book is to systemically deal with the "next best job," when the classical probability theory fails to be valid in these situations.

The sum of random matrices is a sum of linear matrix functions. Non-linear matrix functions are encountered in practice. This motivates us to study, in Chap. 4, the concentration of measure phenomenon, unique to high dimensions. The so-called Lipschitz functions of matrices such as eigenvalues are the mathematical objects.

Chapter 5 culminates for the theoretical development of the random matrix theory. The goal of this chapter is to survey the latest results in the mathematical literature. We tried to be exhaustive in recent results. To our best knowledge, these results are never used in the engineering applications. Although the prerequisites for this chapter are highly demanding, it is out belief that the pay-off will be significant to engineering graduates if they can manage to understand the chapter.

Chapter 6 is included for completion, with the major goal for the readers to compare the parallel results with Chap. 5. Our book "Cognitive Radio Communications and Networking: Principles and Practice" (John Wiley and Sons 2012) contains complementary materials of 230 pages on this subject.

In Part II, we attempt to apply these mathematical tools to different applications. The emphasis is on the connection between the theory and the diverse applications. No attempt is made to collect all the scattered results in one place.

Chapter 7 deals with compressed sensing and recovery of sparse vectors. Concentration inequalities play the central role in the sparse recovery. The so-called restricted isometry property for sensing matrices is another aspect of stating concentration of measure.

A matrix is decomposed into the eigenvalues and the corresponding eigenvectors. When the matrix is of low rank, we can equivalently say the vector of eigenvalues are sparse. Chapter 8 deals with this aspect in the context of concentration of measure.

Statistics starts with covariance matrix estimation. In Chap. 9, we deals with this problem in high dimensions. We think that compressed sensing and low-rank matrix recovery are more basic than covariance matrix estimation.

Once the covariance matrix is estimated, we can apply the statistical information to different applications. In Chap. 10, we apply the covariance matrix to hypothesis detection in high dimensions. During the study of information plus noise model, the low-rank structure is explicitly exploited. This is one justification for putting low-rank matrix recovery (Chap. 9) before this chapter. A modern trend is to exploit the structure of the data (sparsity and low rank) during the detection theory. The research in this direction is growing rapidly. Indeed, we surveyed some latest results in this chapter.

An unexpected chapter is Chap. 11 on probability constrained optimization. Due to the recent progress (as late as 2003 by Nemirovski), optimization with probabilistic constraints, often regarded as computationally intractable in the past, may be formulated in terms of deterministic convex problems that can be solved using modern convex optimization solvers. The "closed-form" Bernstein concentration inequalities play a central role in this formulation.

In Chap. 12, we show how concentration inequalities play a central role in data friendly data processing such as low rank matrix approximation. We only want to point out the connection.

Chapter 13 is designed to put all pieces together. This chapter may be put as Chap. 1. We can see that so many problems are open. We only touched the tip of the iceberg of the big data. Chapter 1 also gives us motivations of other chapters of this book.

The first author wants to thank his students for the course in the Fall semester of 2012: ECE 7970 Random Matrices, Concentration and Networking. Their comments greatly improved this book. We also want to thank PhD students at TTU for their help in proof-reading: Jason Bonior, Shujie Hou, Xia Li, Feng Lin, and Changchun Zhang. The simulations made by Feng Lin, indeed, shaped the conceptions and formulations of many places of this book, in particular on hypothesis detection. Dr. Zhen Hu and Dr. Nan Guo at TTU are also of help for their discussions. The first author's research collaborator Professor Husheng Li (University of Tennessee at Knoxville) is acknowledged for many inspired discussions.

The first author's work has been supported, for many years, by Office of Naval Research (ONR) through the program manager Dr. Santanu K. Das (code 31). Our friend Paul James Browning is instrumental in making this book possible. This work is partly funded by National Science Foundation (NSF) through two grants (ECCS-0901420 and CNS-1247778), Office of Naval Research through two grants (N00010-10-10810 and N00014-11-1-0006), and Air Force Office of Scientific Research, via a local contractor (prime contract number FA8650-10-D-1750-Task 4). Some parts of this book were finished while the first author was a visiting professor during the summer of 2012 at the Centre for Quantifiable Quality of Service in Communication Systems (Q2S), the Norwegian University of Science and Technology (NTNU), Trondheim, Norway. Many discussions with his host Professor Yuming Jiang are acknowledged here.

The authors want to thank our editor Brett Kurzman at Springer (US) for his interest in this book. We acknowledge Rebecca Hytowitz at Springer (US) for her help.

The first author wants to thank his mentors who, for the first time, exposed him to many subjects of this book: Weigan Lin (UESTC, China) on remote sensing,

Zhengde Wu (UESTC, China) on electromagnetics, Shuzhang Liu (UESTC, China) on electromagnetic materials, I-Tai Lu (Polytechnic Institute of NYU) on radio propagation, Lawrence Carin (Duke) on physics-based signal processing, Leopold Felsen on scattering, and Henry Bertoni on radio propagation in wireless channels. His industrial colleagues at GTE Labs (now Verizon Wireless) and Bell Labs (Alcatel-Lucent) greatly shaped his view.

Last, but not the least, the first author wants to thank his wife Lily Liman Li for her love, encouragement, and support that sustains him during the lonely (but exciting) book writing journey—she is always there; and his children Michelle, David and Jackie light his life. This is, indeed, a special moment to record a personal note: This summer his eldest daughter Michelle is going to drive on her own, David is happy in his high school, and Jackie smiles again. Also this summer will mark the time of one decade after his moving back to academia—after spending 8 years in industry. Wring books like this was among his deepest wishes that drove him to read mathematical papers and books while watching his TV for the last two decades. Finally, he is in memory of her mother Suxian Li who passed away in 2006. His father Dafu Qiu lives in China. His parents-in-laws Lumei Li and Jinxue Chen live with him for many years. Their love and daily encouragement really make a difference in his life.

http://www.springer.com/978-1-4614-4543-2

Cognitive Networked Sensing and Big Data
Qiu, R.; Wicks, M.
2014, XXIII, 614 p., Hardcover
ISBN: 978-1-4614-4543-2