# Mathematical neuroscience M394C
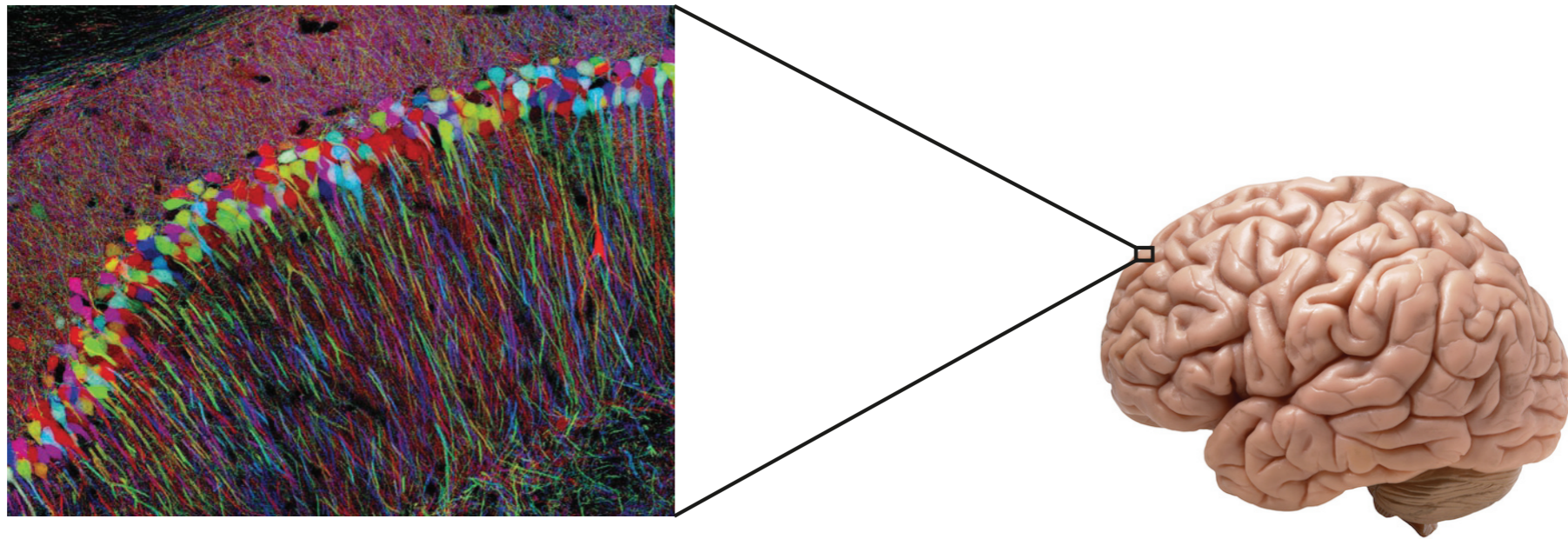
Topics in neural dynamics, information theory, and machine learning

# Mathematical theory
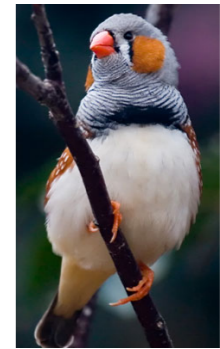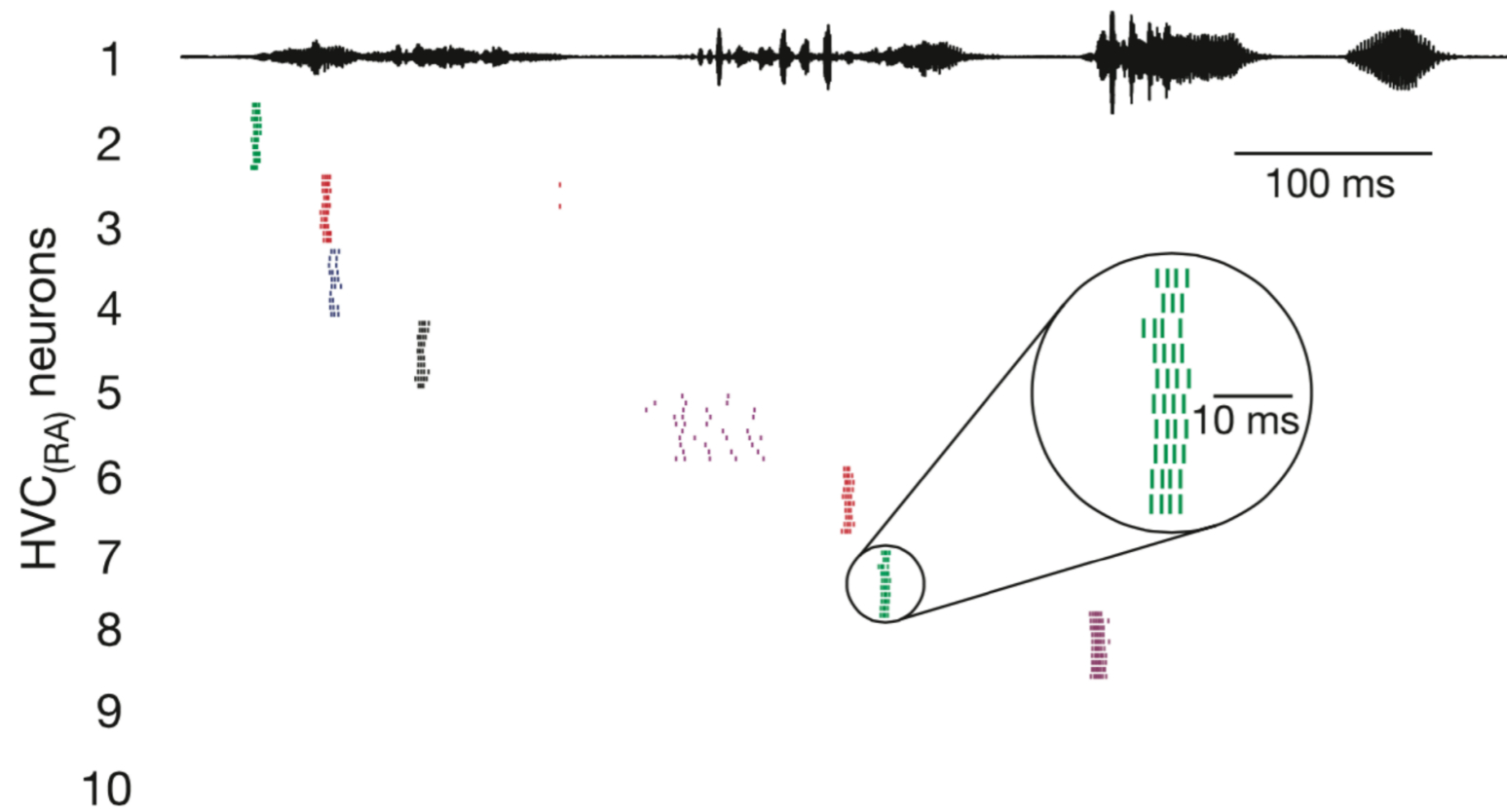
# Network complexity



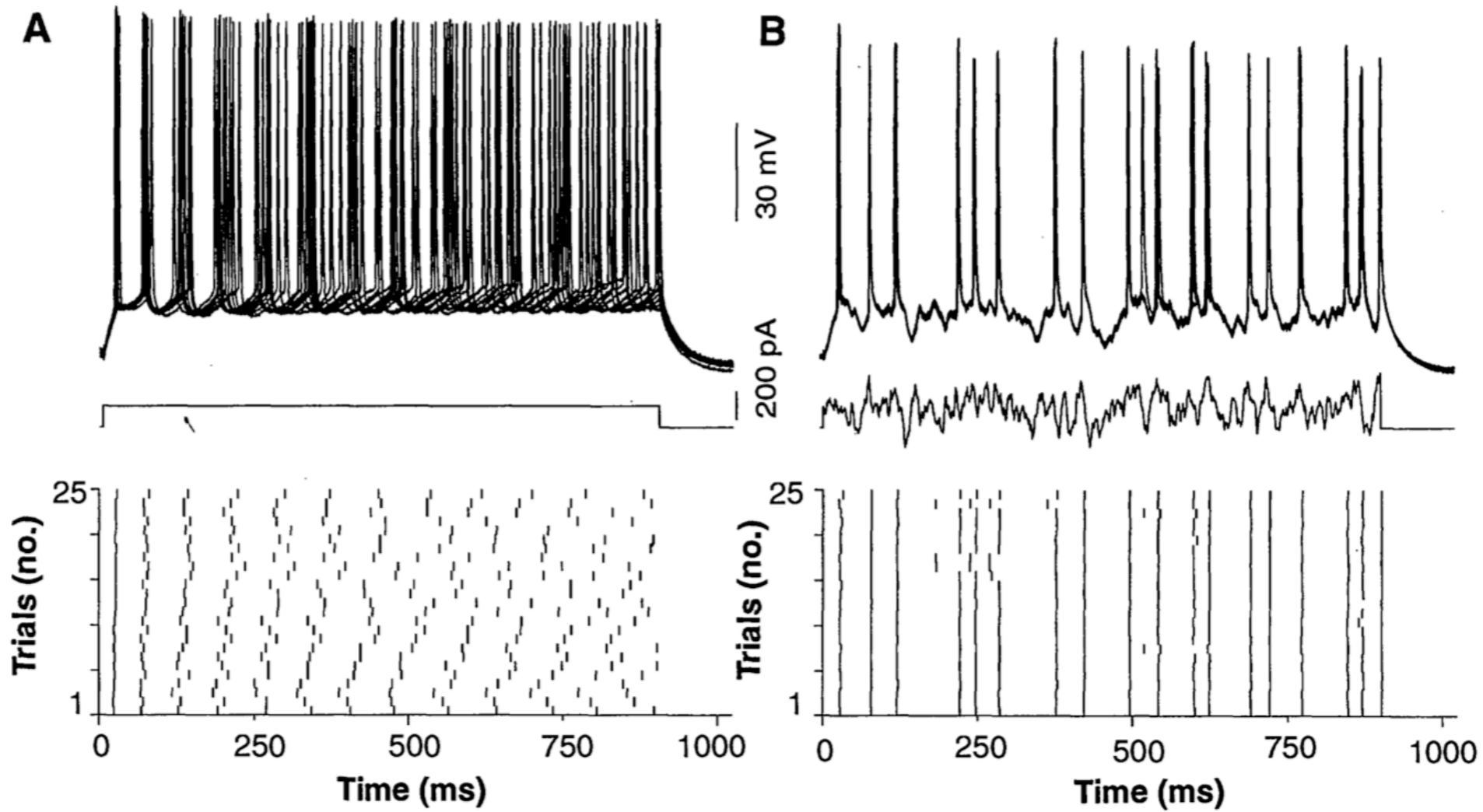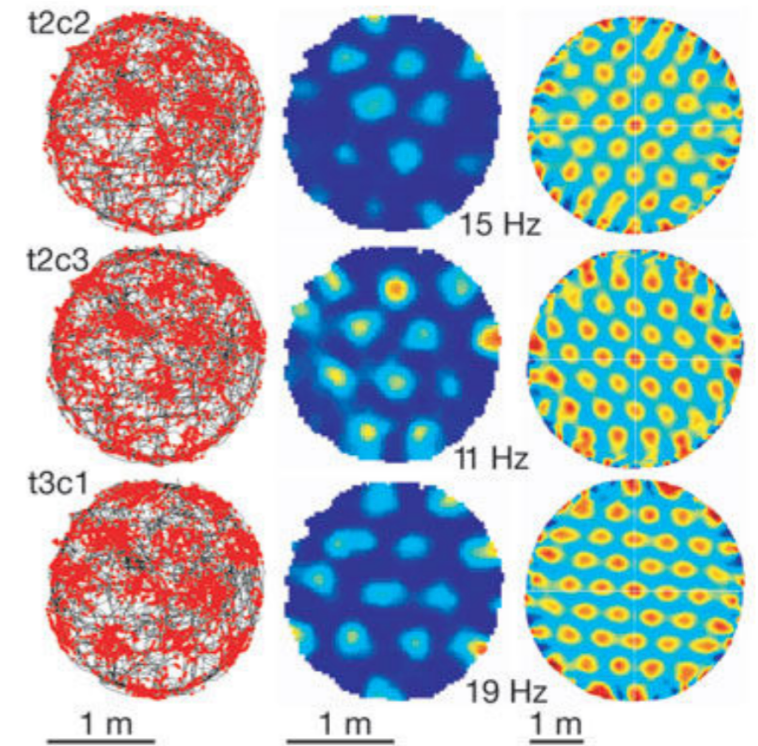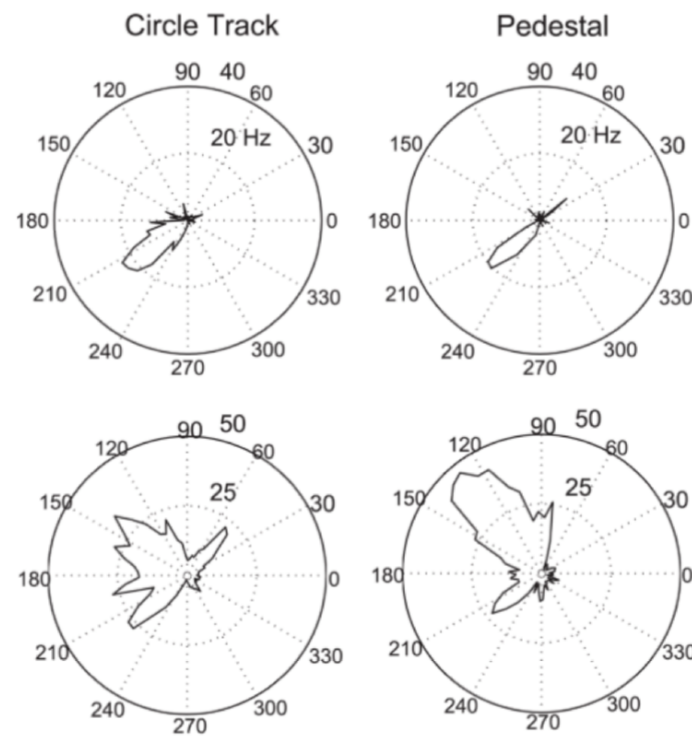100 billion neurons
100 trillion synapses
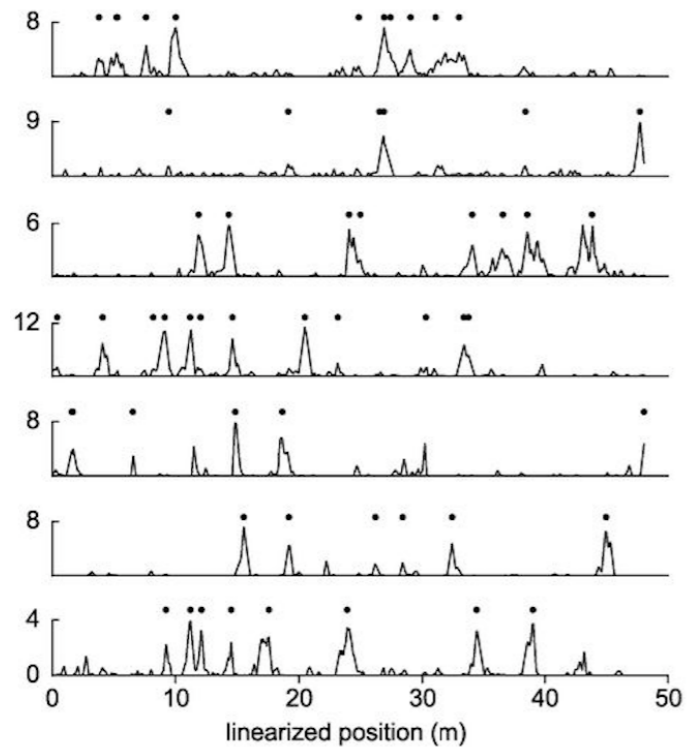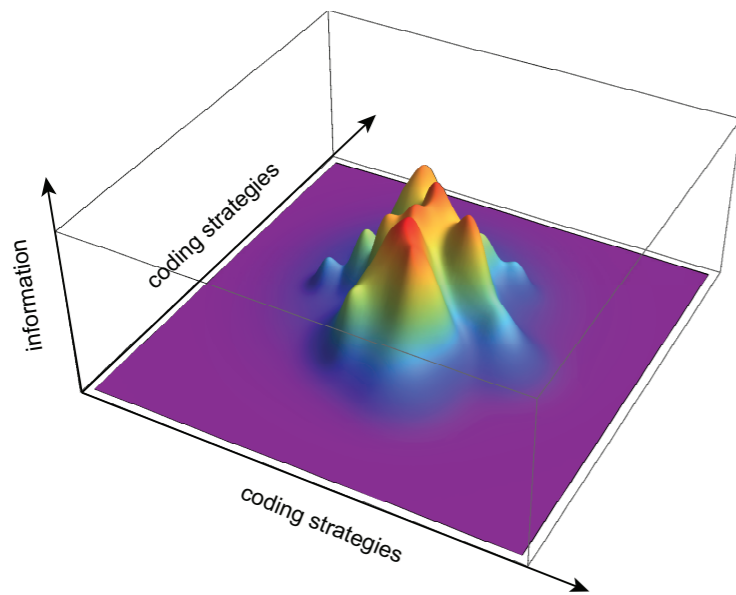
# Coding ambiguity

# Noise

# Heterogeneity

# Sloppiness



Tractable landscape
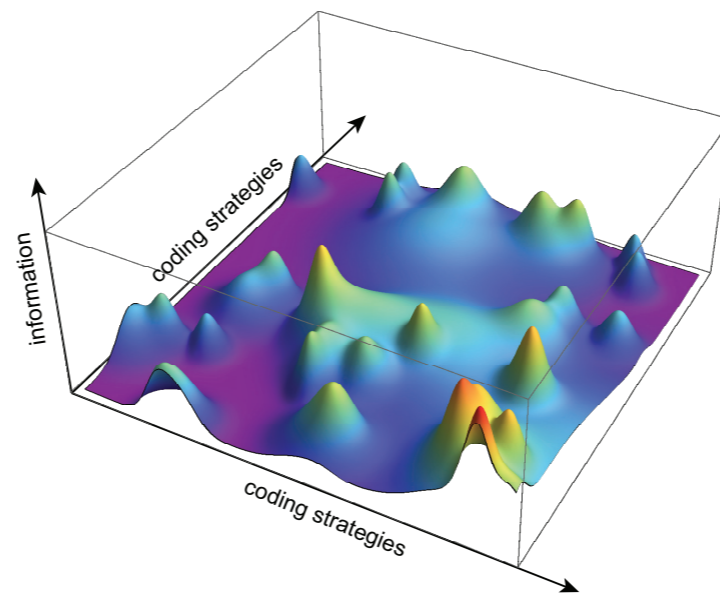
Higly non-convex landscape
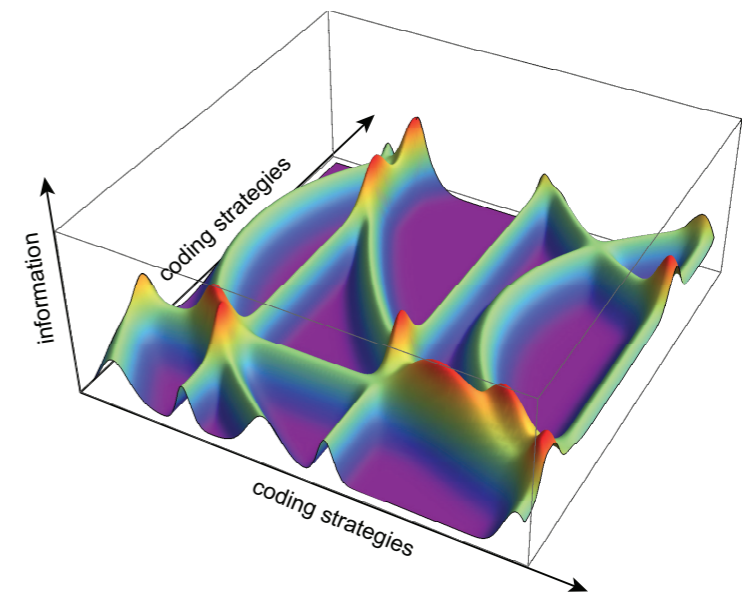
Sloppy  landscape

# Course content

■ **Neural dynamics**

■ **Information theory**

■ **Machine learning**

**Background in neuroscience**



**Theoretical Neuroscience
P. Dayan and L. Abbott**

# Neural dynamics

# Biophysical modeling via dynamical systems

■ **Hodgkin-Huxley model**

■ **Reduced dynamical systems**

■ **Spiking in excitable systems**
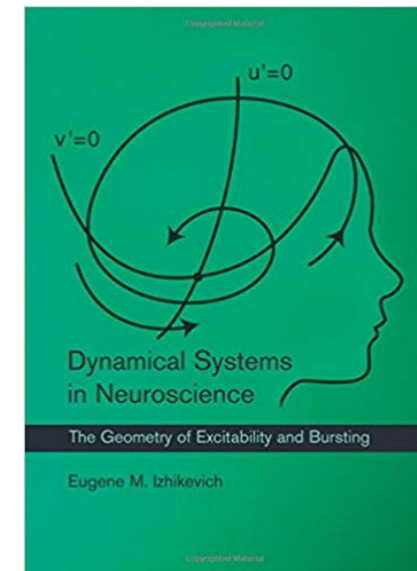


**Dynamical Systems in Neuroscience
E. Izhikevich**

# Bifurcation theory in single neurons

■ **Center manifold reduction**

■ **Normal form theory**

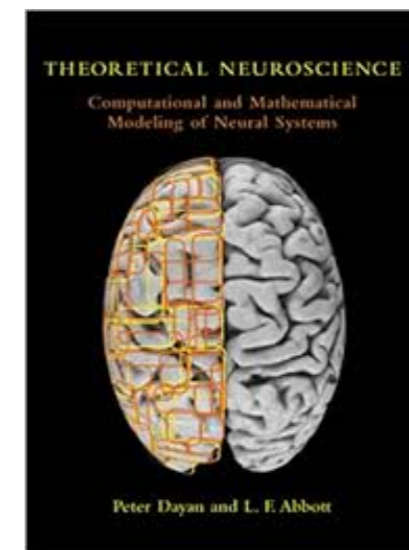■ **Two-dimensional bifurcations**
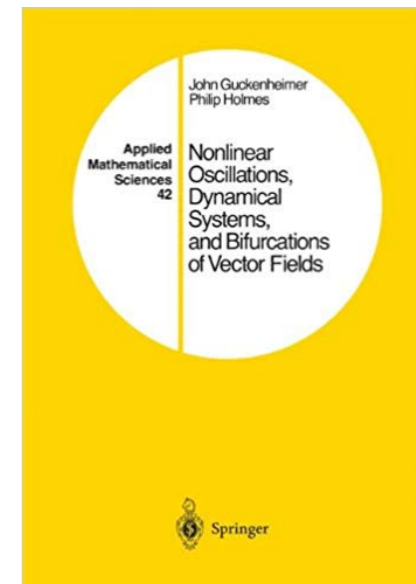
**Nonlinear oscillations, dynamical systems and bifurcation of vector fields**
**J. Guckenheimer and P. Holmes**

# Stochastic modeling of neural variability

■ **Intensity-based models**

■ **Integrate-and-fire models**

■ **Simulation and inference methods**
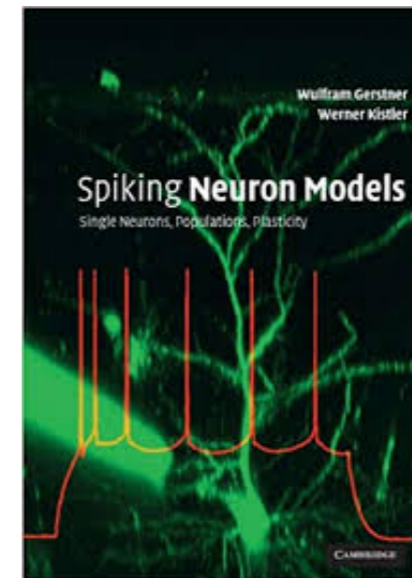


**Spiking neuron models
W. Gerstner and W. Kistler**

# Simplifying mean-field limits for neural networks

■ **Networks in the thermodynamic limit**

■ **Propagation of chaos**

■ **Replica mean-field limit**



**Topics in Propagation of chaos A. Sznitman**

# Information theory

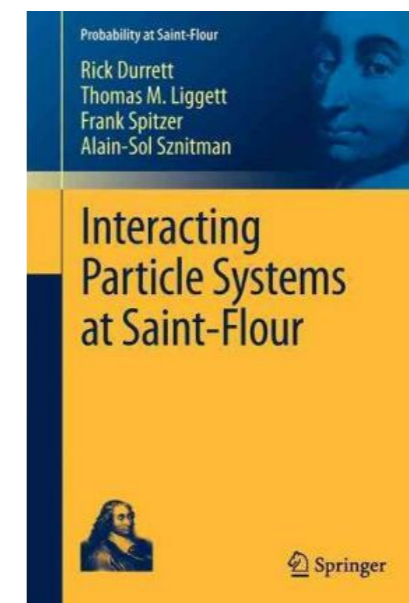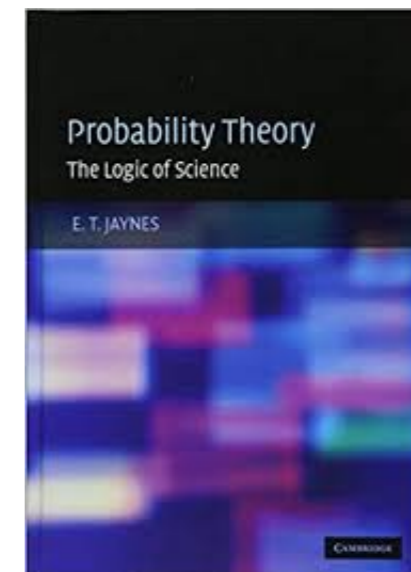# Statistical inference

■ **Maximum entropy methods**

■ **Exponential family of distributions**

■ **Application to inference in neuroscience**

**Probability Theory**
The Logic of Science
E. T. JAYNES
CAMBRIDGE

**Probability theory**
**E. Jaynes**

# Information geometry

■ **Probabilistic models as manifolds**

■ **Fisher metric and information divergence**
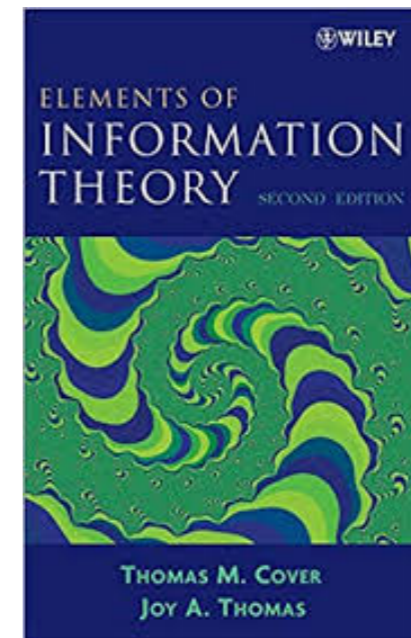
■ **Dual structure of information geometry**
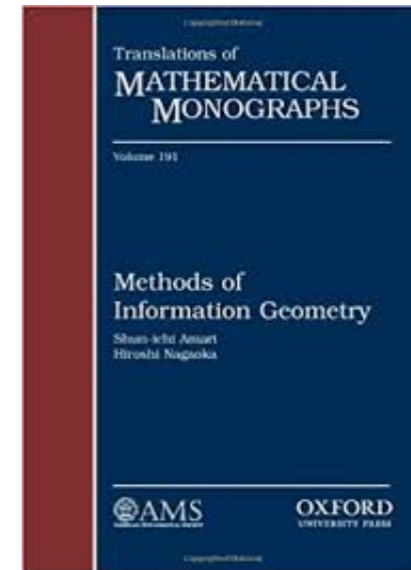
Methods of information geometry
S. Amari

# Basics of information theory

- Mutual information

- Information capacity

- Rate-distortion theory



**Elements of
Information theory
T. Cover and J. Thomas**

# Efficient coding hypothesis

■ **Optimization under constraints of relevance: information bottleneck**

■ **Variational optimization of the Fisher information**
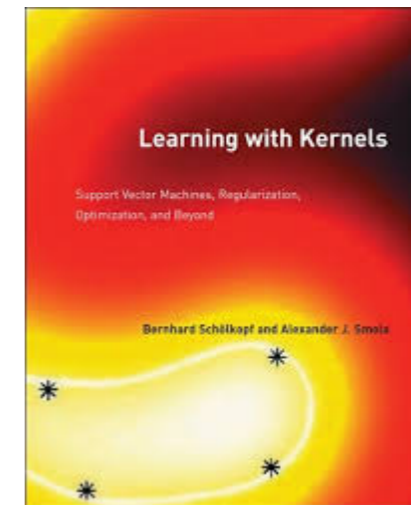
# Machine learning

# Basics of machine learning

- Linear separability and complexity

- Learning via perceptron algorithm

- Linear separability and neural code

# Support-vector machines

■ **Nonlinear separability**

■ **Reproducing-kernel Hilbert space**



**Learning with kernels**
**B. Scholkopf and A. Smola**

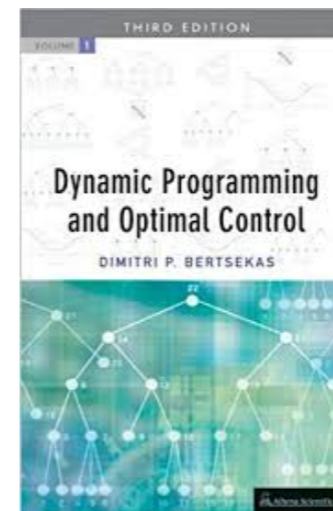# Reinforcement learning



- **Markov decision process**

- **Dynamic programming**

- **Q-learning algorithm**

**Reinforcement learning**

**R. Sutton and A. Barto**

**Dynamic programming and optimal control**

**D. Bertsekas**

# Unsupervised learning methods

■ **Autoencoder networks**

■ **Generative adversarial networks**