System Identification, Lecture 12

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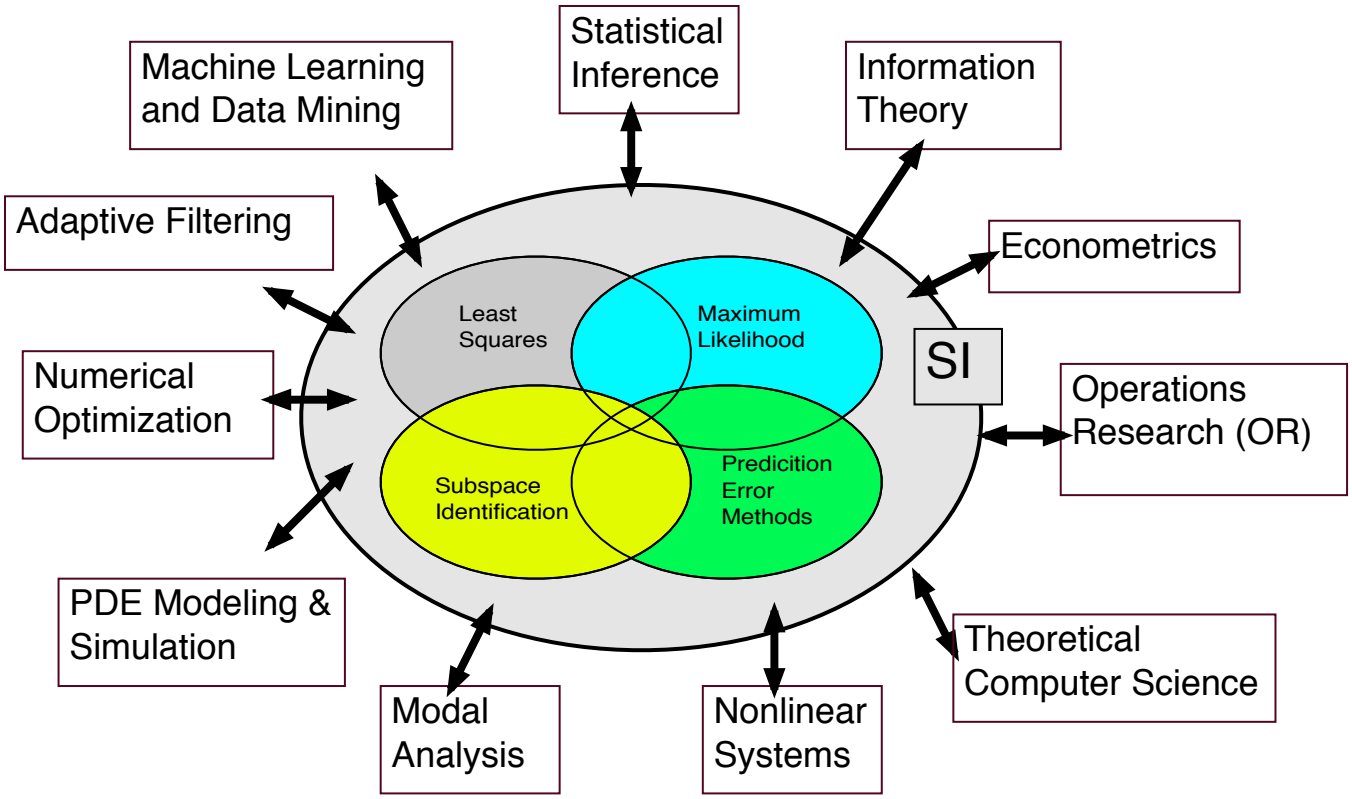
Overview Part II

1. State Space Systems.
2. Subspace Identification.
3. Further Topics.
4. Identification of Nonlinear Models.
5. Wider View.

System Identification: A Wider View



1. SI = Recovery/Approximation of Systems from Experiments.

2. Characteristic: Dynamical Nature, Model Structures.

3. Interdisciplinary.

Adaptive Filtering

1. What: "Track optimal filter $\mathbf{h}_t$ which purifies the signals." Ex.:

   (a) Initialize $f_0 = 0_d$, $t = 0$
   (b) Predict $f_{t-1}(\mathbf{x}_t)$ and measure feedback $e_t = (y_t - f_{t-1}(\mathbf{x}_t))$
   (c) Update $f_t = f_{t-1} + g(e_t)$
   (d) Repeat for $t = 1, 2, \ldots$.

2. Why:

   - Communication.
   - Acoustics.
   - Filters.

3. Results:

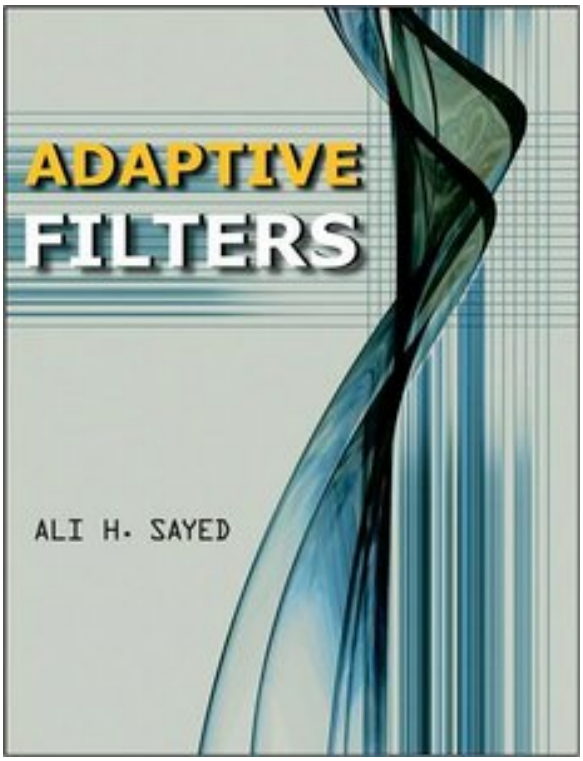
   - Differential Equation.
   - Algorithmic.
   - Equalization.
   - Efficiency.

- Time-varying.

4. Relevance 2 SI:

   - D/A and anti-aliasing filters.
   - Equalization and communication.
   - Block-adaptive filters and networks.

5. Text:



Numerical Analysis

1. What: "Numerical analysis is the study of algorithms that use numerical computation (as opposed to general symbolic manipulations) for the problems of mathematical analysis (as distinguished from discrete mathematics)."

2. Why: continuous $\rightarrow$ finite.

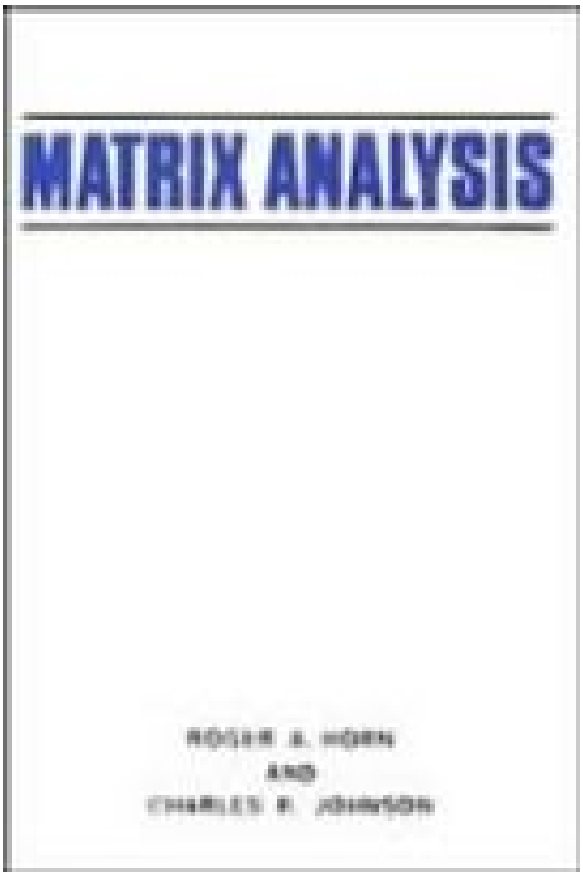
3. Results:

   - Matrix manipulations.
   - Characterizations.
   - Decompositions.

4. Relevance 2 SI:

   - Subspace ID.
   - LAPACK/NUMPACK.
   - Distributed Computation.

5. Text:



Numerical Optimization

1. What:

$$\min_{\theta \in \mathbb{D}} J(\theta) \quad \text{s. t.} \quad \theta \in \Theta$$

2. Why: Local/Global?

3. Results:

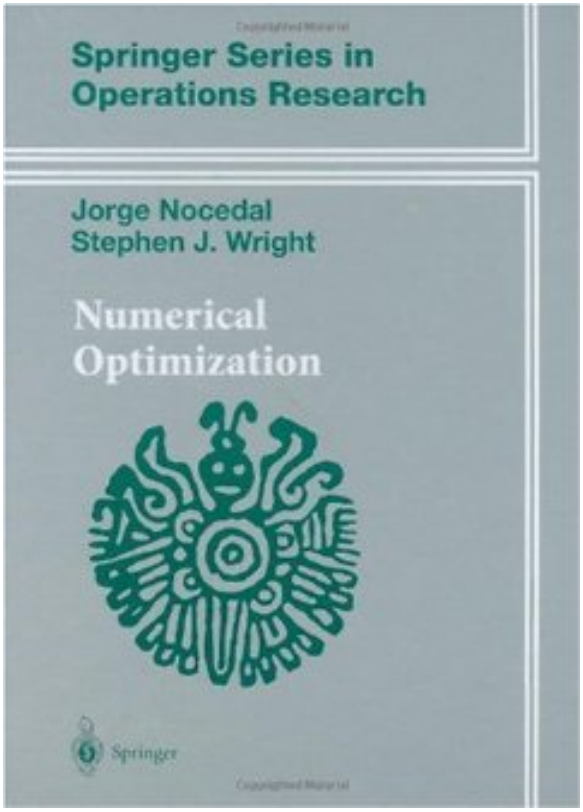
   - LS versus non-LS.
   - Linear versus nonlinear.
   - Convex versus Non-convex.
   - Heuristics.
   - Speed of convergence & Comp. demand.

4. Relevance 2 SI:

   - Toolbox and Embedded Systems.
   - Practical and theoretical efficient algorithms.
   - Differential vs. non-differential.
   - Recursive Identification.

- Motor.
- How to interpret numerical/asymptotic result?

5. Text:



Theoretical Computer Science

1. What: "The design and study of algorithms."

2. Why:

   - Efficient algorithms.
   - Computational and Memory Complexity.

3. Results:

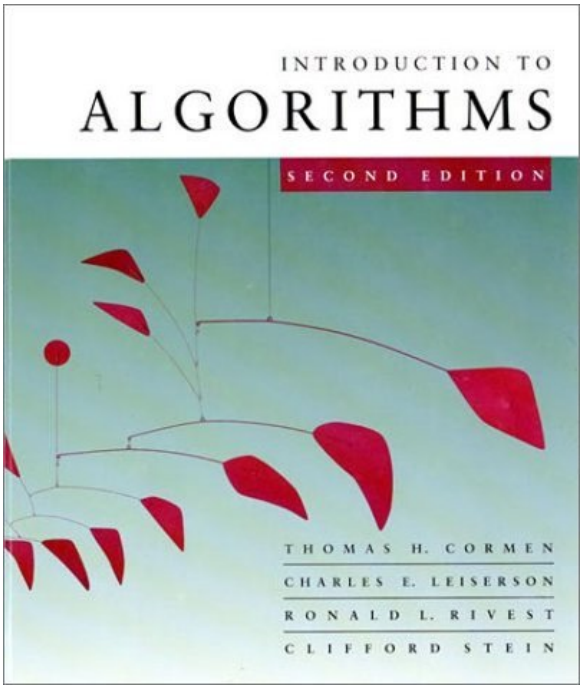
   - Sorting, ..., bin-packing.
   - P versus NP.
   - Randomization.
   - Heuristics.
   - Reduction to numerical analysis.
   - Beyond matrices.

4. Relevance 2 SI:

   - Sequential and Online.

- Nonlinear ID.
- Greedy strategies.

5. Text:



Operations Research

1. What: "Operations research is an interdisciplinary mathematical science that focuses on the effective use of technology by organizations."

2. Why:

   - WWII.
   - Optimal Strategies.
   - DP.
   - Abstractions (models).

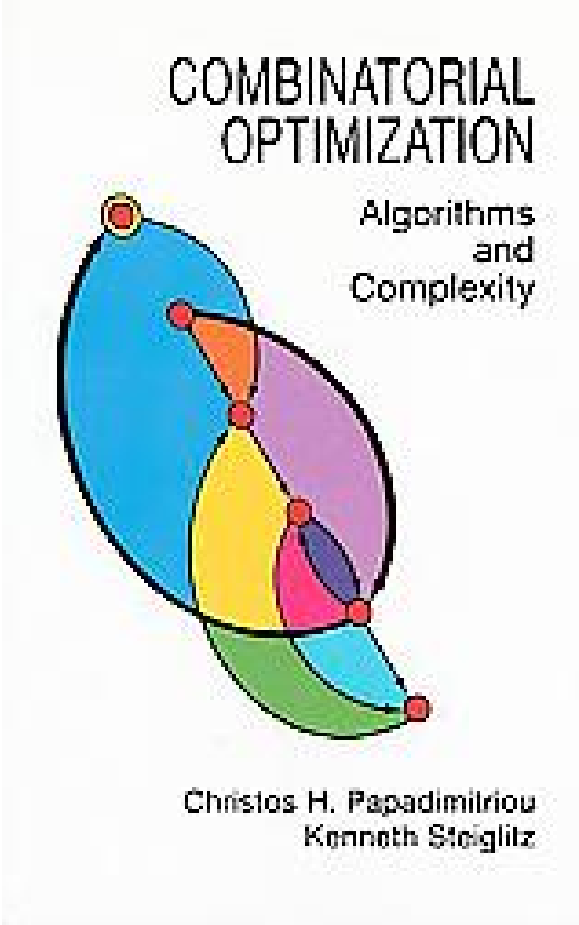
3. Results:

   - MINCUT - MAXFLOW - linear Programming.
   - Combinatorial Optimization.
   - Matching, Allocation, Scheduling, Paths and Routing.
   - Sequential Testing and Quality Control.

4. Relevance 2 SI:

- Combinatorial Models.
- Networked Systems.
- Optimization.

5. Text:



Machine Learning and Data Mining

1. What: "A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P, if its performance at tasks in T, as measured by P, improves with experience E."

$$\mathbf{y} \approx f(\mathbf{X})$$

2. Why:

   - Nonlinear models and predictors.
   - How to characterize and relate many different tools?

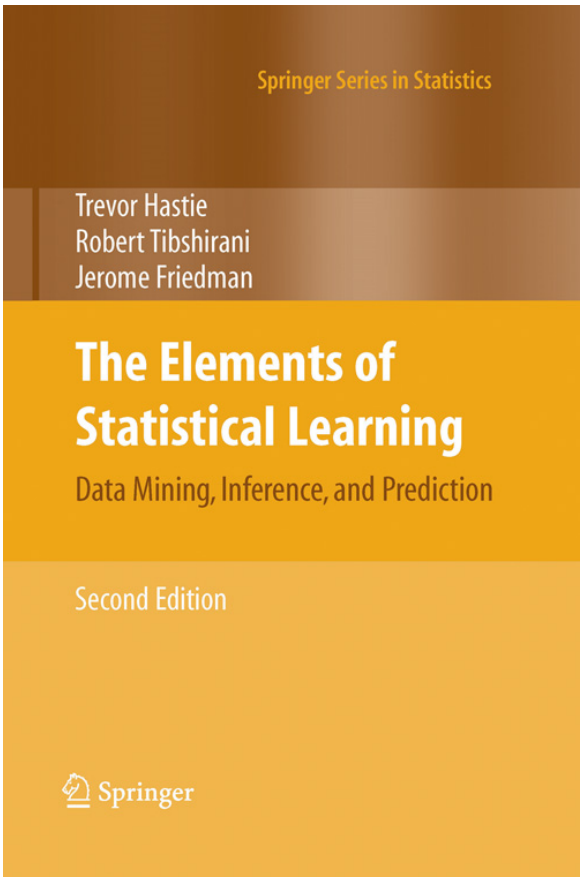
3. Results:

   - Toolboxes (SVM, splines, Decision trees).
   - ML matured $\rightarrow$ parameters 2 functions.
   - Algorithms.
   - Complexity Control and Generalization.

- Theoretical ML vs. Applications (DARPA).

4. Relevance 2 SI:
   - Off-the-shelve tools.
   - Generalization Analysis.
   - MATLAB, WEKA, Python, ...

5. Text:



Statistical Inference

1. What: "Estimation and inference of Statistical models generating the data, from data." ex.

$$X \sim \mathcal{N}(0_n, \Sigma)$$

   ML:

$$\hat{\Sigma} = \underset{\Sigma}{\operatorname{argmax}}\, L(X_n; \Sigma)$$

2. Why:

   - Stochastics as an abstraction of irrelevant, individual effects.
   - Optimal model $\rightarrow$ Optimal predictor?
   - Averaging behavior.

3. Results:

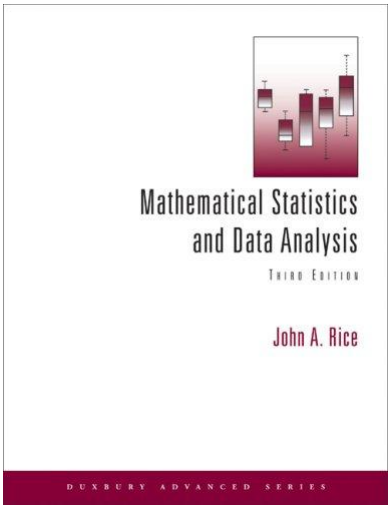
   - Stochastic Processes, IID.

- Statistical Models.
- ML.
- CLT and Cramer-Rao.
- Hypothesis Testing.
- Finite sample results.
- Beyond ML: Penalized ML, U-, L-, M-, V-, R-statistics.

4. Relevance 2 SI:

- Timeseries.
- Often nonlinear in parameters.
- Often Newton-Raphson.
- Inference and covariance.
- R, SAS, Python, stata, SPSS, Matlab, Excel.
- Data visualization tools.

5. Text:


Mathematical Statistics
and Data Analysis
Third Edition
John A. Rice
DUXBURY ADVANCED SERIES

Information Theory

1. What: "Modeling as communication - a model as summary of the data."

2. Why:

   - Choice of model subjective.
   - Objective guidelines?
   - Fundamental limits.

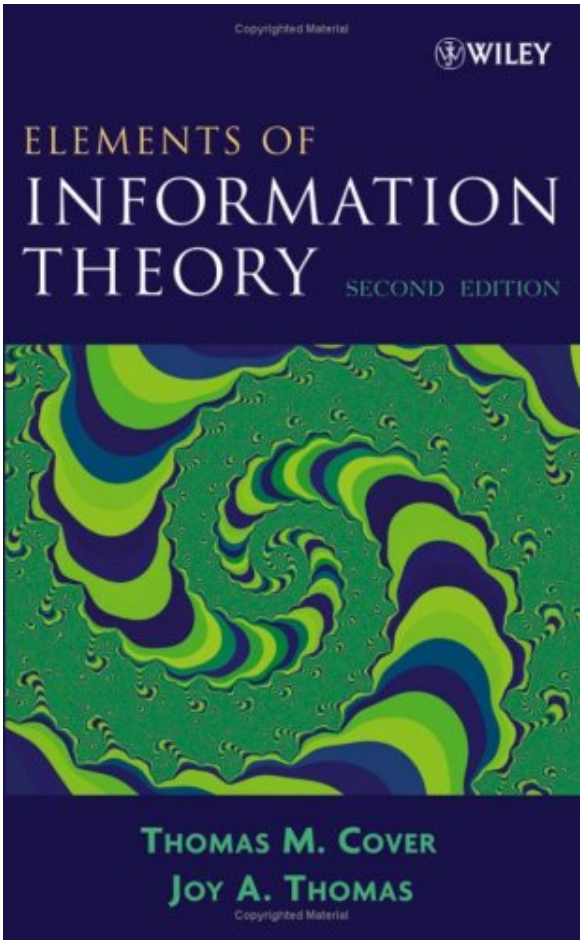
3. Results:

   - Shannon's source coding theorem $|\text{com}(X)| \geq h(X)$
   - Shannon's noisy source coding theorem $|\text{com}(X)|/|X| \geq \frac{C}{1-h(X)}$
   - Entropy, KL, MI.
   - MDL.
   - rate Distortion theory.

4. Relevance 2 SI:

- Compression.
- Foundation to Stochastic.
- Gambling, Investment and Universal rules.

5. Text:



Econometrics and Financial Matters

1. What: "Econometrics studies statistical properties of econometric procedures"

2. Why:

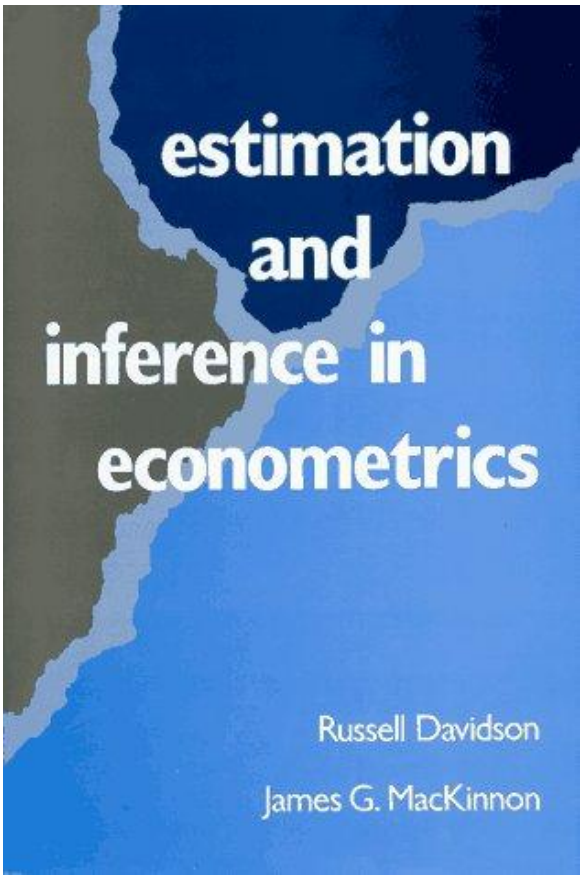
3. Results:

   - Noise and correlations.
   - Jumps and outliers.
   - Variance Stabilizing transformations.
   - Gambling and Maximal profit strategies.
   - Stochastic Calculus ($\hat{I}$to)

4. Relevance SI:

   - Timeseries modeling.
   - Preprocessing.
   - Continuous time.

5. Text:


estimation
and
inference in
econometrics
Russell Davidson
James G. MacKinnon

Nonlinear Systems

1. What: "Study of the dynamics arising from nonlinear systems."

2. Why:

   - Models $\rightarrow$ I/O Behavior.
   - I/O Behavior ? models?

3. Results:

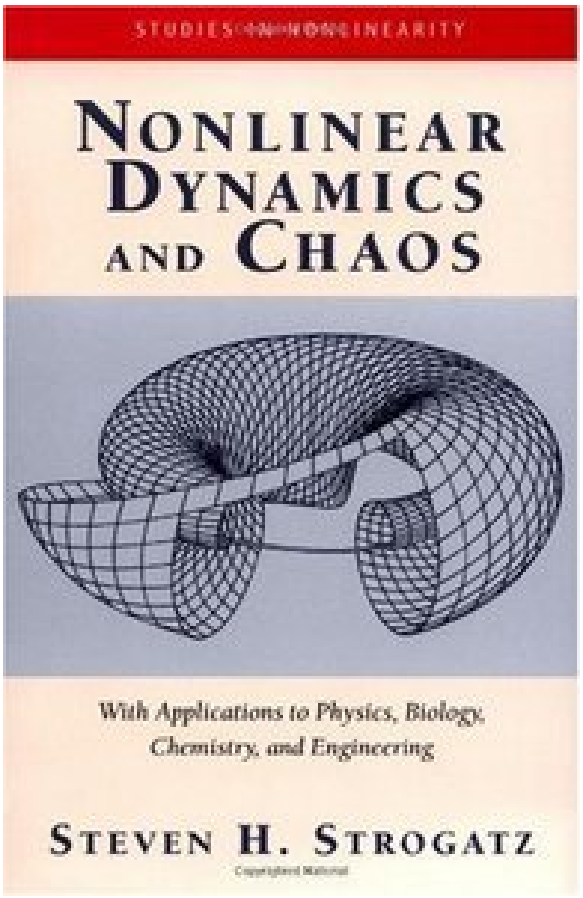
   - Oscillators.
   - Bifurcation Diagrams.
   - Long range prediction.
   - Stability and Limit Cycles.

4. Relevance SI:

   - Diagnostics to Identified Nonlinear model.
   - Observed behavior $\rightarrow$ Model structure?

- Phase

5. Text:


STUDIES IN NONLINEARITY
NONLINEAR DYNAMICS AND CHAOS
With Applications to Physics, Biology, Chemistry, and Engineering
STEVEN H. STROGATZ

Conclusions

To remember

- Least Squares.
- Extensions.
- Toolbox.
- Tuning.