Quantitative Methods for Cognitive Scientists

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SBSG 2308

https://canvas.eee.uci.edu/courses/16991

Experimentation & Data Analysis

- **Interpreting** experimental (behavioral) data (*e.g.* Statistical Analysis)
- **Analyzing** neuroimaging data (*e.g.* EEG, fMRI)

Cognitive Modeling

- **Understanding** how the mind works
- **Predicting** how people & animals behave in new situations
- **Treating** pathology in cognition
- **Building** intelligent artificial systems and agents

The Impact of Big Data on Cognitive Sciences

- We are in an era where analyse are routinely made over huge amounts of data. For example:
  - Decision making (Netflix, Amazon etc.)
  - Natural Language (Wikipedia)
  - Problem Solving (Document editing histories)
  - Perception and Vision (Image repositories)
  - Information trends (Google, Twitter)
  - Neurosciences (Human Connectome Project)

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  - Neurosciences (Human Connectome Project)
- Leveraging big data requires quantitative methods
- Understanding underlying mechanisms from data requires models.

Class Objectives

1. Introduction to methods for quantiative modeling in cognitive sciences:

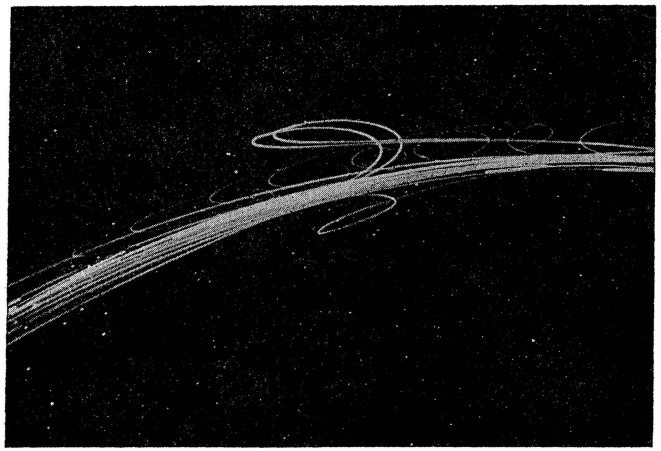
- Parameter Estimation
- Dealing with Uncertainty
- Classification with neural networks
- Clustering and Dimensionality Reduction

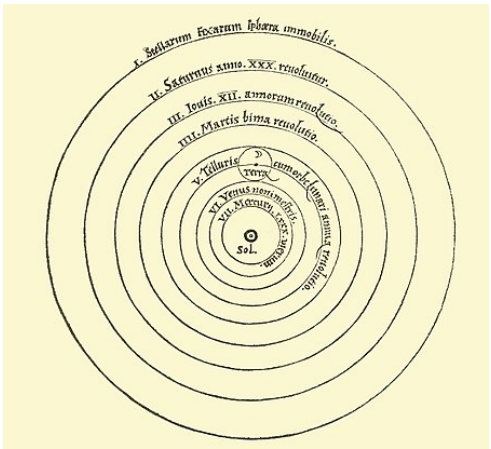
2. Consolidate Mathematical Skills:

- Probability Theory
- Linear Algebra and Calculus
- Optimization

The Importance of Modeling

Position of planets in the night sky over time:





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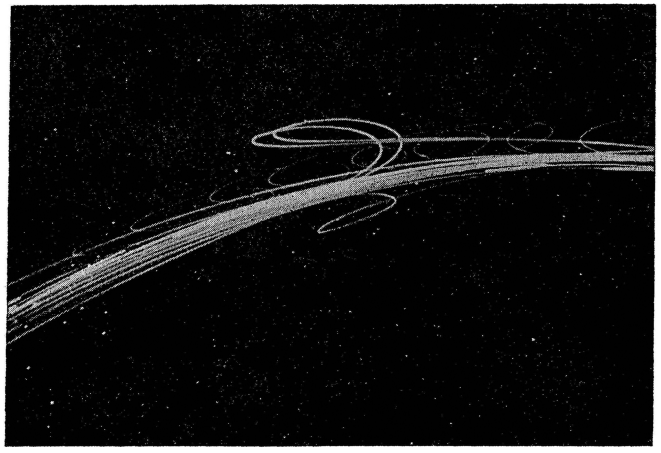

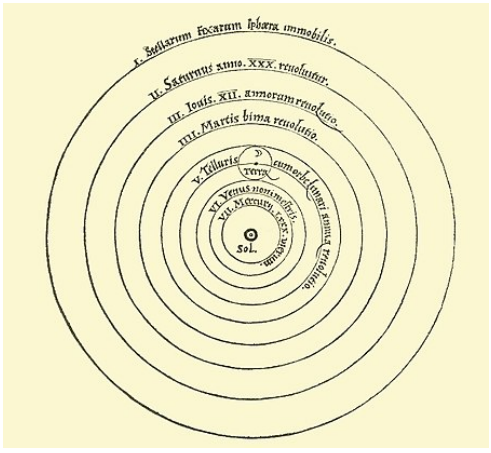

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- Without a model it is very difficult to describe this motion, namely the "retrograde effect"

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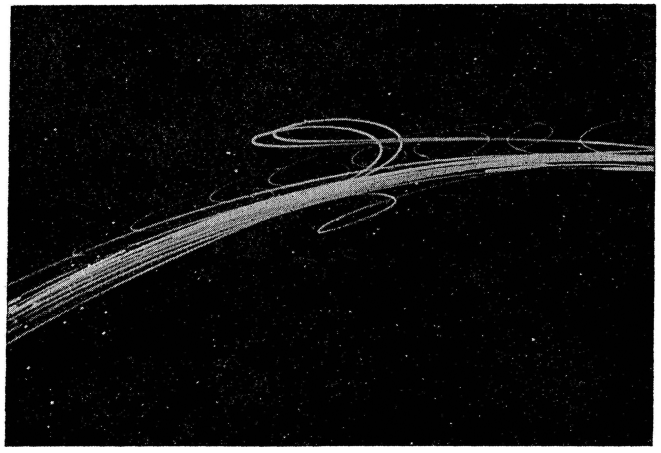
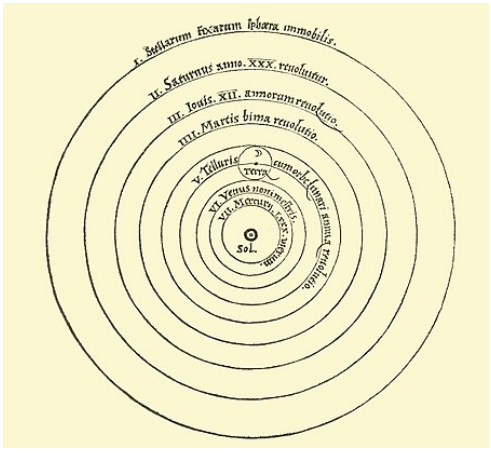
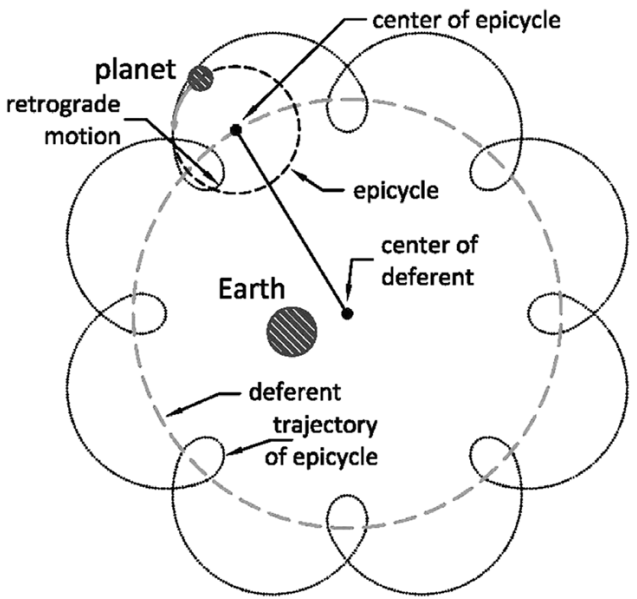




- How can one describe the trajectories of the planet?
- Without a model it is very difficult to describe this motion, namely the "retrograde effect"
- Copernicus' heliocentric model revealed that retrograde motion arises from the fact that the planets travel at different speeds along their orbits;

The Importance of Modeling

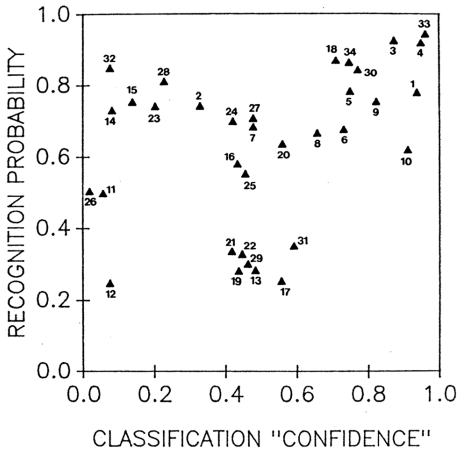
- Several models are possible, and can explain data. For example the following geocentric model can also explain the retrograde motion with reasonable accuracy
- The geocentric model and the heliocentric model both provide good accuracy.

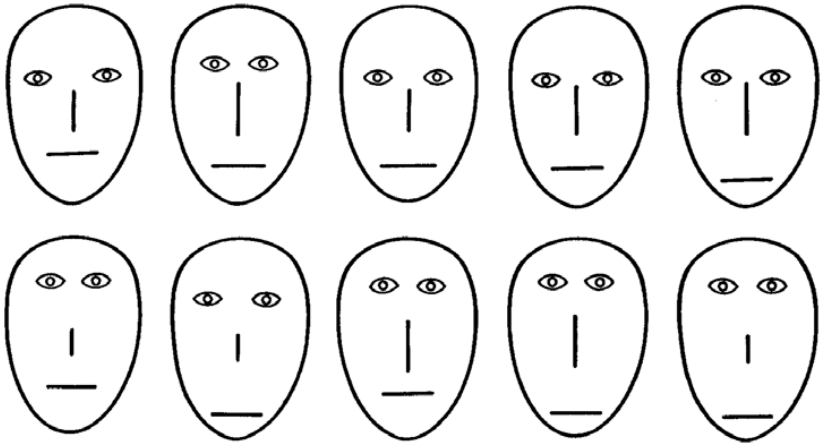


Quantitative Methods are essential for Modeling and Data Analysis

1. To describe, predict and understand the data, it is essential to use quantitative, mathematical models.
2. Data analysis and verbal theorizing are often insufficient because they cannot give testable, quantitative predictions
3. Several models exists. Modelers must use quantitative evaluation and intuition to select the model.

Models in Cognitive Science: Categorization

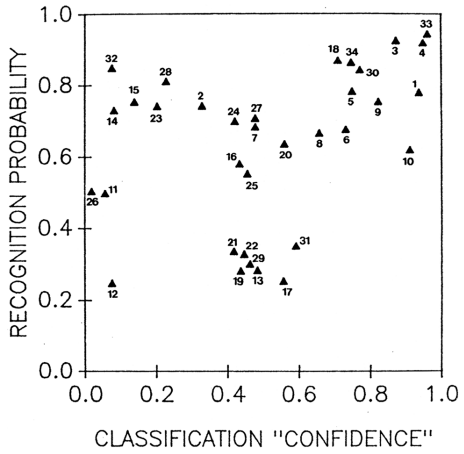


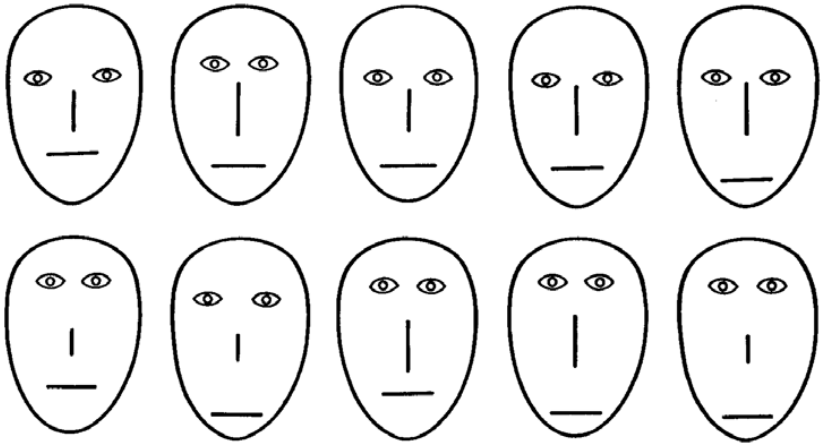


- Subjects were trained to classify a small set of cartoon faces into two categories

Nosofsky, (1991)

Models in Cognitive Science: Categorization





- Subjects were trained to classify a small set of cartoon faces into two categories
- Next, subjects were presented with a larger set of faces, including those used at training. For each face, subjects made two decisions:
  1. Which category the face belonged to and the confidence of that decision (X-axis)
  2. Whether or not the face had been shown during training (Y-axis).

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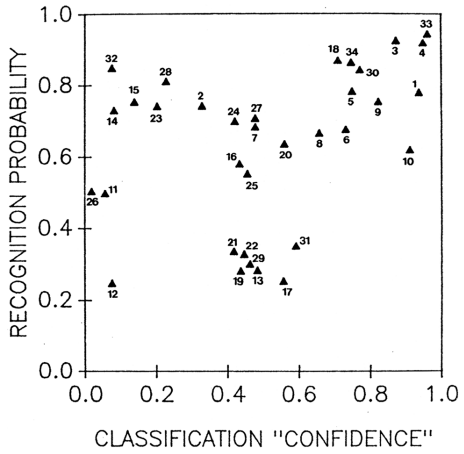

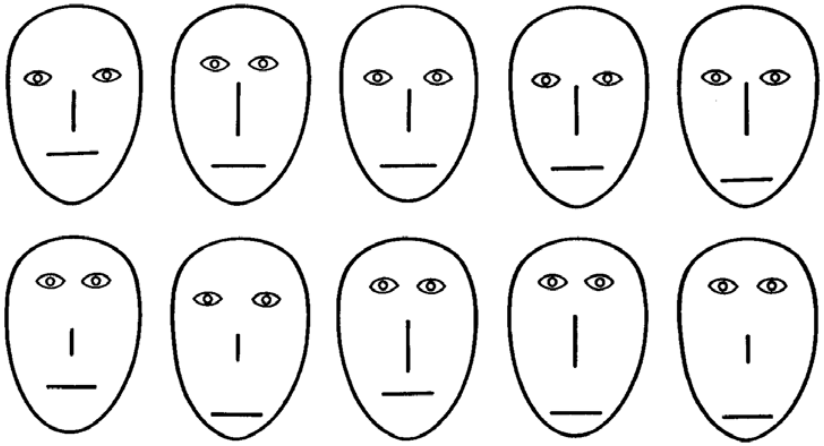

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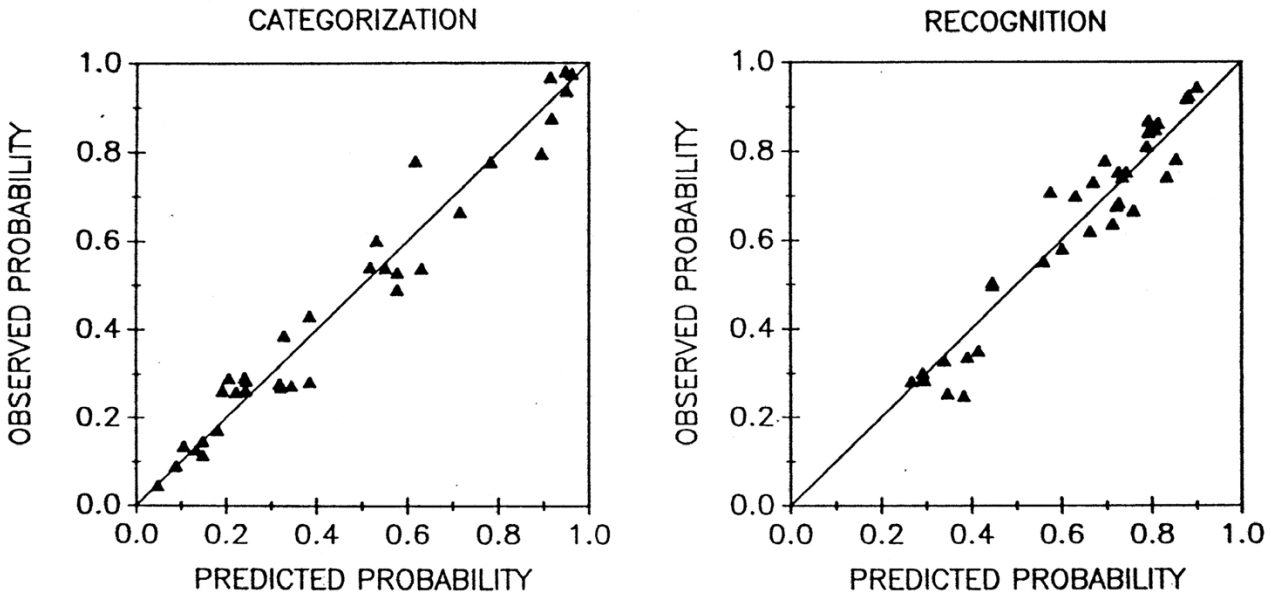
  1. Which category the face belonged to and the confidence of that decision (X-axis)
  2. Whether or not the face had been shown during training (Y-axis).
- Are recognition and classification tasks closely related? Are the same processes responsible for both?

Nosofsky, (1991)

A model called “Generalized Context Model” (GCM) gives the following predictions for both recognition and classification:



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- That these accurate predictions were provided by the same model may mean classification and recognition can be related to each other

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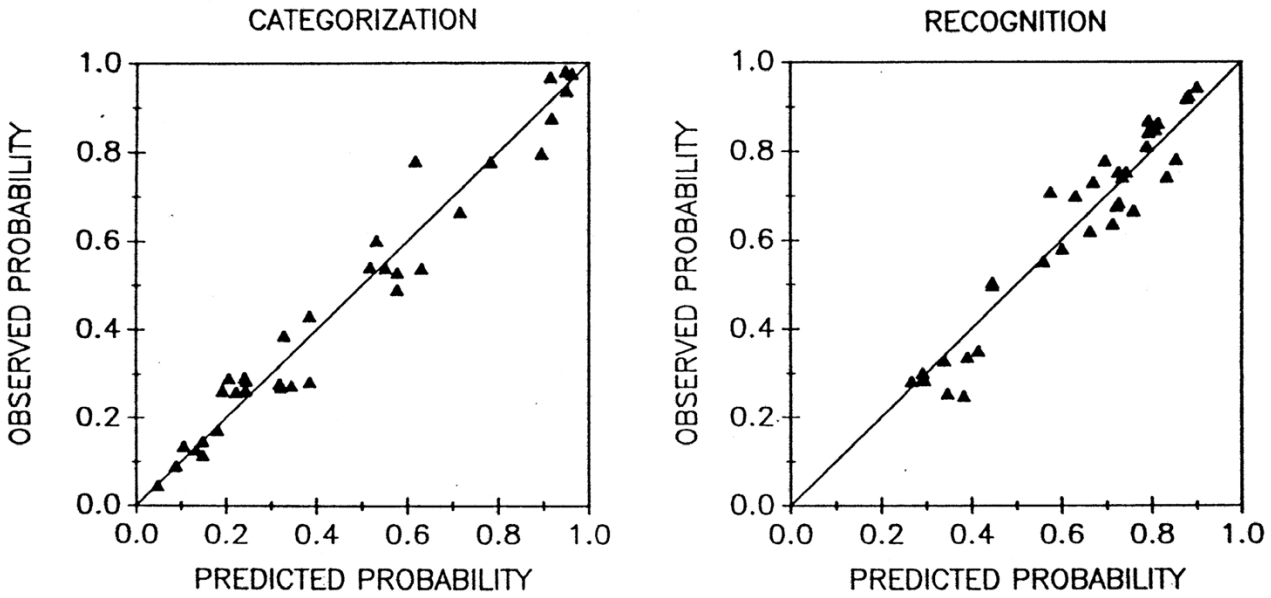

- Perfect prediction implies all points align on the diagonal.
- That these accurate predictions were provided by the same model may mean classification and recognition can be related to each other
- With the data alone, it would be difficult to make this conclusion

Class Organization

Tentative Class Plan

Introduction: Sequential Sampling Models ..... Week 1
Parameter Estimation ..... Week 2
Probability theory: Probabilistic Processes ..... Week 3
Maximum Likelihood Parameter Estimation ..... Week 4
Bayesian Inference and Parameter Estimation ..... Week 5
Midterm ..... April 30 2019
Linear Algebra: Vectors and Matrices ..... Week 6
Neural Network Models ..... Week 7
Linear Algebra: Eigenspaces ..... Week 8
Principal Component Analysis ..... Week 9
Combining Data from Multiple Participants ..... Week 10

References: Course material is inspired from the following resources (all books are available online)


C.M. Bishop. *Pattern recognition and machine learning*. Springer-Verlag New York, Inc. Secaucus, NJ, USA, 2006. ISBN: 0387310738.


Simon Farrell and Stephan Lewandowsky. *Computational modeling of cognition and behavior*. Cambridge University Press, 2018.


Ian Goodfellow, Yoshua Bengio, and Aaron Courville. *Deep learning*. MIT press, 2016.


Gilbert Strang, Gilbert Strang, Gilbert Strang, and Gilbert Strang. *Introduction to linear algebra*. Vol. 3. Wellesley-Cambridge Press Wellesley, MA, 1993.

Software

Class lectures and some assignments will involve basic Python programming. In-class demonstrations will use Python. The following Python packages will be used

- numpy (installed by default on UCI computers)
- scipy (installed by default on UCI computers)y
- matplotlib (installed by default on UCI computers)
- pyTorch (instructions for installation will be given in class)

Examination questions will **not** involve programming

Office Hours and Teaching Assistant

Office Hours:

- **Neftci:** We 1:00PM - 5:00PM by appointment at SBSG 2308

Grading Plan

1. Assignments (40%)
2. Midterm (20%)
3. Final (40%)

Important Dates:

Midterm	April 30 2019
Final Q & A	June 6 2019
Final Exam	Jun. 8-13 2018

No make-up examinations.

Reports and assignments must be submitted before the deadline posted with each assignment sheet.