Visual Intelligence

Cognitive Science 412

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Overview:

Although seeing appears to be effortless, in fact, every aspect of the world that we perceive must be painstakingly constructed by our visual system. The images projected on our retinas are two-dimensional, unstructured, and always changing. The world as we see it, however, is three-dimensional, highly structured (consisting of objects and surfaces embedded in 3D space), and fairly stable. How is it possible for our brains—indeed any computational system—to transform incoming 2D images into a stable representation of a three-dimensional environment. This course aims to introduce students to the study of visual intelligence from a computational point of view. The emphasis is on understanding the representations that our visual systems generate, and the computations that are used to generate them.

Learning Goals:

Learning goals include: (1) To develop scientific and critical reasoning skills; (2) To learn how the eyes and brain function, and contribute to our perception of the world; (3) To learn about computational and behavioral methods in the study of visual perception; (4) To appreciate the complexities of the connection between the mind, the brain, and the world.

Grading:

Homework assignments: 40%

Final exam: 40%

Class participation: 20%

Text and Readings:

Most readings will consist of original research papers and book chapters (see below for a week-by-week reading schedule). In addition, the following will serve as a background text, and chapters from this book will often be assigned as readings.

Textbook:

Frisby, J. P. & Stone, J. V. (2010). *Seeing: The Computational Approach to Biological Vision.* (MIT Press)

Reading Schedule:

Week 1: Introduction

- Chapter 1 from: Hoffman, D. (1998). *Visual Intelligence: How we create what we see.* W. W. Norton & Company.

Week 2: Inverse Optics and the Fundamental Problem of Vision

- Adelson, E. H. & Pentland, A. (1996). The perception of shading and reflectance. In: D. Knill & W. Richards, *Perception as Bayesian Inference*.

Week 3: Computation and Representation

- Chapter 1 from: Marr, D. (1982). *Vision: A computational investigation into the human representation and processing of visual information.* W. H. Freeman Press.
- "Representations" (pp. 15-29). Chapter 2 from: Gallistel, C. R. (1993). The Organization of Learning. MIT Press: Cambridge, MA.
- In the Frisby & Stone text, please consult Chapter 1.

Week 4: Early vision: From the eye to the brain

- Chapter 4, pp. 145-158, from: Palmer, S. E. (2000). *Vision Science: Photons to Phenomenology.* MIT Press.
- In the Frisby & Stone text, please consult Chapters 5 and 6.

Week 5: Visual representation of shape

- Hoffman, D. & Richards, W. (1984). Parts of recognition. *Cognition, 18,* 65-96.
- Pasupathy, A. & Connor, E. (2002). Population coding of shape in area V4. *Nature Neuroscience, 5,* 1332-1338.

Week 6: Inverse probabilities and Bayes Rule

- Chapters on the basics of probability theory from Hacking's book. (For Bayes Theorem, see pp. 69-77).
- Chapter 2 ("Bayesian updating") from *Memory and the Computational Brain: Why Cognitive Science will transform Neuroscience,* by C. R. Gallistel and A. P. King (2009). Wiley-Blackwell.
- In the Frisby & Stone text, please consult Chapter 13.

Week 7: Visual perception as probabilistic inference

- M. Albert, D. Hoffman. *Genericity in spatial vision.* In D. Luce, K. Romney, D. Hoffman, & M. D'Zmura (Eds.), Geometric Representations of Perceptual Phenomena: Articles in Honor of Tarow Indow's 70th Birthday. 1995, Erlbaum, New York.
- Mamassian, P., Landy, M. and Maloney, L. T. (2003). Bayesian modeling of visual perception. In: R Rao, B. Olzhausen and M. Lewicki (Eds.), *Probabilistic models of the brain: Perception and neural function.* Cambridge, MA: MIT Press.
- In the Frisby & Stone text, please consult Chapter 13.

Week 8: Perceptual Grouping and Contour Integration

- Field, D., Hayes, A. & Hess, R. (1993). Contour integration by the human visual system: evidence for a local "association field". *Vision Research, 33, 2*, 173-193.
- In the Frisby & Stone text, please consult Chapter 7 (for Gestalt "grouping principles").

Week 9: Natural Image Statistics (or "Where do Priors come from?")

- Geisler, W. S., Perry, J. S., Super, B. J., & Gallogly, D. P. (2001). Edge co-occurrence in natural images predicts contour grouping performance. *Vision Research, 41(6),* 711–724.

Week 10: Visually-guided motor behavior as optimal decision-making

- Koerding, K. (2007). Decision theory: What "should" the nervous system do? *Science, 318,* 606-610.
- Trommerhaeuser, J., Maloney, L. T., and Landy, M. S. (2008). Decision making, movement planning, and statistical decision theory. *Trends in Cognitive Sciences, 12,* 291-297.

Week 11. Fundamentals of binocular vision; cues to depth; stereopsis - depth from disparity; binocular rivalry

- Julesz, B., (1964) "Binocular depth perception without familiarity cues," Science 145, p. 356-362.

- Kovács I, Papathomas TV, Fehér A, Yang M. (1996) "When the brain changes its mind: Interocular grouping during binocular rivalry," *Proceedings of the National Academy of Sciences USA*, 93, 15508-15511
- Logothetis, N. K., Leopold, D. A. & Sheinberg, D. L. (1996) What is rivalling during binocular rivalry?" *Nature (London)* **380,** 621–624.
- Textbook by Frisby & Stone, pp. 419-434, 451, 454-464.

Week 12. Computational models for stereopsis; Marr & Poggio global algorithm; Frequency domain analysis; combining cues for depth

- Marr D., Poggio T. (1976) Cooperative computation of stereo disparity. Science, Oct 15;194(4262):283-287.
- Held, R.T., Cooper, E.A., and Banks, M.S. (2012). Blur and disparity are complementary cues to depth. Curr. Biol. 22, 426–431. (Read's paper below introduces Held et al.'s 2012 paper)
- Jenny C.A. Read (2012) Visual Perception: Understanding Visual Cues to Depth, Current Biology 22, RT163-R165. (This paper introduces Held et al.'s 2012 paper)
- Textbook by Frisby & Stone, pp. 434-443

Week 13: Motion: psychophysics and models – motion aftereffect

- J. A. Movshon and W. T. Newsome (1992) "Neural Foundations of Visual Motion Perception", Current Directions in Psych Science, vol 1, 35-39.
- Adelson, E. H. & Bergen, J. R. (1985) Spatiotemporal energy models for the perception of motion. J. Opt. Soc. Am. A 2, 284-299.
- Lu Z-L, Sperling G (1996) "Three systems for visual motion perception", Current Directions in Psychological Science, 5, 44-53,
- See also ReichardtMotionModelCartoon.ppt
- Textbook by Frisby & Stone, pp. 325-330, 334-338, 340-350.

Week 14: Converging evidence for top-down influences in vision - 3D illusions - hollow mask and reverspectives - clinical relevance

- Papathomas TV, Bono L. "Experiments with a hollow mask and a reverspective: Top-down influences in the inversion effect for 3-D stimuli," *Perception,* **33**, 1129-1138, 2004.
- Keane B. P., Silverstein, S. M., Wang, Y., Papathomas T. V., (2013) "Reduced depth inversion illusions in schizophrenia are state-specific and occur for multiple object types and viewing conditions," *Journal of Abnormal Psychology*, 122(2), 506-512.
- Frisby & Stone, pp. 22-23, 162, 171, 201.

Course Policies:

1. Attendance and missed classes: Class attendance and participation are essential components of this course. You must attend each class prepared to discuss the assigned reading(s). You are responsible for the material covered in any class you miss. If you must miss a class, or even a portion of a class, be sure to find out what was covered by borrowing notes from another student. Then, to get additional explanation, or to ask questions, come to office hours.

2. Plagiarism/Cheating: Rutgers has a clear policy on Academic Integrity with very low tolerance for any form of cheating or plagiarism. This policy will be adhered to strictly. Please be sure to acquaint yourself with this policy: http://academicintegrity.rutgers.edu/academic-integrity-policy/
   A useful interactive tutorial on plagiarism can be found here: http://library.camden.rutgers.edu/EducationalModule/Plagiarism/

3. Accommodations for students with disabilities: Students with disabilities requesting accommodations must follow the procedures outlined at https://ods.rutgers.edu/ students/ registration-form. Full disability policies and procedures are at https:// ods.rutgers.edu/