Vision and the Visual System

Davida Y. Teller

Edited by John Palmer
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Editor’s Forward

Davida Teller worked on this book until 2009. At that time her health prevented her from finishing and she passed away in 2011. The book was well along but incomplete. I have edited the book with the goal of making it accessible to others. As much as possible, my approach was to preserve Davida’s voice by removing material that was incomplete rather than adding material.

This printing includes all of the text, figures and references for the 26 chapters written by Davida. Many of the figures are hand drawn or modified from previously published figures with citation of the source. Permission to reproduce these materials will be requested when the book is complete.

I intend to do one more round of editing of this book and send it to the publisher in July 2014. For those reading it, please tell me about any errors you find (jpalmer@uw.edu). I do not expect to do any major revisions, but I do wish to remove as many errors as possible. For those of you that have seen the version distributed in 2013, the major revisions are in the last 3 chapters.

The editing of this book was done together with my friends and colleagues. The first round of copyediting, gathering figures, and finding references was done by my student Serap Yigit-Elliott. Thanks Serap! It was supported by the Department of Psychology at the University of Washington at the direction of its chair, Professor Sheri Mizumuri. The second round of editing was done in conjunction with teaching “Davida’s vision course” at the University of Washington in the summer of 2012. I thank all of the students of that course for their suggestions. The third round of editing was aided by comments and support from many colleagues including David Brainard, Cathleen Moore, Zygmunt Pizlo, Dina Popovkina, Erik Runeson and Jason Webster. In particular, Maria Pereverzeva read every chapter and made detailed comments. Special thanks goes to my wife, Zelda Zabinsky, for her suggestions and enduring support. In addition, I thank Davida’s husband, Tony Young, for his encouragement and help assembling the materials. Most importantly, I thank Davida Teller for her trust in allowing me to edit her work.

John Palmer
Seattle, Washington
12 April 2014
Preface

Vision science can be defined as the study of vision, the visual system, and the relations between the two. When we study vision, we use psychophysical and perceptual techniques to describe what and how well we see: how good are our spatial and temporal resolution? What is our color vision like? What are the properties of motion perception, form perception, object recognition? When we study the visual system, we use the techniques of neuroscience to describe the properties of the neural machinery – the optics, photochemistry, anatomy and/or physiology of the visual system – that makes seeing possible. And when we study the relationships between the two, we try to answer the question: How do the properties of the neural machinery leave their marks on the properties of perception?

In the terminology of this book, a *causal story* is an attempt to answer a question of this kind. For example, the statement that the shape of the scotopic spectral sensitivity curve is caused by the absorption spectrum of the photopigment rhodopsin is a (correct) causal story. So would be the statement that visual acuity is limited by the optical quality of the eye. (It would be incorrect, but a causal story nonetheless). I argue below that the most fundamental goal of vision science lies in the discovering and testing of causal stories.

Almost no one starts his or her intellectual life as a vision scientist. Most of us are trained in one or another of the classic disciplines: physiology, psychology, medicine, philosophy, physics, engineering, computer science, and so on. But eventually we may find ourselves working on a problem defined in the parent discipline, but whose answer impinges on the properties of vision and/or the visual system. One day our hearts suddenly beat faster with the insight that we might be able to contribute to the understanding of how people actually see. We’re drawn to thinking of the visual system as a *system*, with vision as one of its high-level properties. We suddenly want to know how the topic we are studying fits into an understanding of the visual system as a whole. We’re hooked – we’ve just become a vision scientist.

The conceptual base of vision science is remarkably varied and remarkably rich. This is partly because each new vision scientist brings along facts and concepts from his or her parent disciplines. Every few years new ways of thinking arrive from the parent disciplines. With a lot of intellectual work and many graduate seminars, the new concepts are eventually either found to enhance the old or are weeded out, and the discipline is the richer for it. An addiction to new concepts can keep a person in vision science for a lifetime.

But by the same token, vision science can be difficult for the beginning student to penetrate. This is partly because the conceptual base is so broad, and the factual base so extensive. But it’s also because, as I mean to convince you, causal stories – explaining perceptual facts on the basis of neural facts – are a philosophically tricky matter.

In writing this book, I have had two goals: an initial goal which I chose, and a later one that
forced itself upon me. The initial goal was to write a standard textbook – an introduction to vision science. I particularly wanted to weave together the concepts from the different parent disciplines. I wanted to make them mutually consistent, and accessible to beginners migrating into vision science from other disciplines. In particular, whenever a concept came up with which I had initially had particular trouble, I have tried to explain it in detail, with particular attention to the aspect with which I initially had trouble.

But as time and drafts went on, a second goal forced its way into the book. Again, the vision scientist’s question is the question of causal stories: How do the properties of neural signals at the various levels of the visual system cause the properties of our perceptions? More deeply, where do hypotheses about causal stories come from, how are they tested, and by what criteria are they judged? How can we tell a good one from a bad one? I had done some prior work in this area (Teller, 1984), and found myself inevitably drawn back to it.

As it turns out, there has been remarkably little explicit analysis of these questions in the vision literature. Consequently, causal stories can be difficult for the newly arriving student to evaluate. The second goal of the book, then, is to attempt to provide an extended, consistent analysis of the logic and the forms of argument used in vision science in general, and in causal stories in particular.

The format and content of this book are as follows. We begin with an explicit treatment of some of the kinds of propositions that enter into arguments about causal stories. Then, after an introduction to psychophysical techniques, we step through the visual system in the usual order – optics, photochemistry, photoreceptors, retinal processing, and so on. In each case, I provide at least a thumbnail sketch (and often a more extended treatment) of the properties and workings of the particular stage of processing. I then build upon this material to tell and evaluate one or more causal stories about how each level of visual processing leaves its marks on our perception.

For instructors, each chapter is meant to correspond to an individual lecture. The book has been used in teaching a 10-week course with 26 lectures of an hour and a half each. The material is suitable for graduate students or advanced undergraduates with a previous introductory course on sensation and perception.

Finally, a note about DT: As all of its practitioners know, science and philosophy are intensely personal passions. I find I can communicate that passion best to students by including personal anecdotes and making personal appearances in the book. But use of the first person in written work was beaten out of me in the third grade, and makes me uncomfortable still. Since the students in my lab have called me “DT” for many years, DT has become my professional alter ego. She makes her presence known throughout the book. She feels free to express her opinions, and to suggest that the reader stop and think at certain points. Also, she feels free to just stop and wonder about things. Of course I do not claim that all the questions DT wonders about are original – surely most of them have been treated better by others. The goal is not to claim originality, but to model the sense of wonder that science engenders, and expose the students to the siren song of the next question down the road.

Davida Y. Teller (aka DT)
Seattle, Washington
September 2007
Acknowledgements

In 1970, Tom Cornsweet published an introductory text on visual science, entitled *Visual Perception*, (Academic Press). It is still read for its lucid accounts of the relationships between physics, physiology and perception. Although I have had to depart from his leisurely style of explanation because so much more is known by now, Tom’s writing has nonetheless provided a model for this book.

Since 1995, several new books on vision science have been published by friends and colleagues. I have used them shamelessly as reality checks, and to educate myself on the parts of visual science that I knew the least about, and I thank the authors for their contributions to my education:

- Brian Wandell’s *Foundations of Vision* (1995), Sinauer Associates,
- D. Milner and M. Goodale’s *The Visual Brain in Action* (1995), Oxford University Press,
- Bob Rodieck’s *The First Steps in Seeing* (1998), Sinauer Associates,
- Bruce Goldstein’s *Sensation and Perception* (1999), Brooks/Cole,
- Clyde Oyster’s *The Human Eye: Structure and Function* (1999), Sinauer Associates,
- Stephen Palmer’s *Vision Science: Photons to Phenomenology* (1999), MIT Press,
- Mike Levine’s *Fundamentals of Sensation and Perception* (2000), Oxford University Press,


Personal thanks must begin with Dr. Maureen (Mo) Powers, who started this book with me, and who produced early drafts of some of the chapters. Unfortunately, changes in her life led her to withdraw from the book early in the writing process. Mo brought activation energy and enthusiasm to the project, along with the conviction that writing a book was actually possible. Well begun is half done. (Well, not really, but it made all the difference.) Without Mo’s enthusiasm, this book wouldn’t have happened. Thanks, Mo.

I also especially thank my long-time colleague and friend, John Palmer, for challenging my thinking at many junctures over the years.

I thank a number of other colleagues for discussions, email conversations and reading chapters of the manuscript: Steve Buck, Tom Cornsweet, Dennis Dacey, Anita Hendrickson, Don Hood, Temy Kennedy, Mike Landy, Barry Lee, Walt Makous, John Maunsell, Suzanne McKee, Matt McMahon, Bill Newsome, Orin Packer, Joel Pokorny, Fred Rieke, Michael Rudd, Michael Shadlen, Julie Schnapf, Steve Shevell and forgotten others. In addition, I thank the students in my vision class who have read whatever chapters were available, and who annually rekindled my will to continue.

In my career I have had four mentors who most effectively challenged my intellect. They
are the Gestalt psychologist Hans Wallach; the philosopher Michael Scriven; the engineer-turned-vision-scientist Tom Cornsweet, and the optometrist-turned-vision-scientist Gerald Westheimer. All communicated to me their passion for ideas. And their collective wisdom can be summarized in two words: Think harder.

Finally, I thank my husband, Tony Young, for making the usual sacrifices an author demands of her family. I also thank him for using his skills as a photographer to provide some of the illustrations included in this book. We have had happy times searching the world for just the right image to illustrate one perceptual concept or another. The series of pictures on the development of vision in infants exists because of his creative skills and imagination.
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Part I

INTRODUCTIONS, OPTICS AND TRANSDUCTION