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978-1-107-03434-1 - Simplicity in Vision: A Multidisciplinary Account of Perceptual Organization

Peter A. Van Der Helm

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SIMPLICITY IN VISION

A Multidisciplinary Account of Perceptual Organization

Simplicity in Vision discusses the neuro-cognitive process that takes the light in our eyes as input and enables us to perceive scenes as structured wholes consisting of objects arranged in space. Any scene can be interpreted in numerous ways, so it is amazing that this automatic process usually yields one clear interpretation which, moreover, is usually sufficiently accurate to guide our actions. This book explores the intriguing idea that this interpretation is the one which reflects the simplest organization of the scene. Building on theoretical and empirical evidence from a wide range of scientific disciplines, it addresses fundamental questions such as: Are simplest interpretations of scenes sufficiently reliable to guide us through the world? What is the nature of the regularities that may be exploited to obtain simplest interpretations? How can the simplest interpretation of a scene be selected from among numerous alternatives, and how is this process neurally realized?

This richly illustrated book on human perceptual organization presents a truly multidisciplinary approach to fundamental issues at the crossroads of experimental psychology, cognitive science, neuroscience, artificial intelligence research, mathematics, computer science, graph theory, evolutionary biology, and philosophy of science. Among other things, the author has developed a mathematical characterization of visual regularity as having a hierarchically transparent holographic nature, which explains much of human symmetry perception. To account for the high combinatorial capacity and speed of the human perceptual organization process, he developed transparallel processing by hyperstrings. This form of processing is feasible in classical computers and is as powerful as quantum computers promise to be. It is proposed to explain neuronal synchronization, yielding a concrete picture of flexible cognitive architecture implemented in the relatively rigid neural architecture of the brain.

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and our beautiful daughters Fheonna, Laura, and Vera

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Preface

Human vision research aims to understand the neuro-cognitive process that, taking the light in our eyes as input, enables us to perceive scenes as structured wholes consisting of objects arranged in space. This perceptual organization process is believed to be one of the automatic brain processes that underlie consciousness and, thereby, virtually every impression we experience and virtually every action we undertake. In other words, we may take this process for granted in our dealings with the world, but it is a basic mechanism not only in daily life but also in nearly every scientific research domain. Human vision research is an exception in that it takes this mechanism as the very topic of study.

It recognizes that the perceptual organization process, by all accounts, must be very complex and yet very flexible. To organize meaningless patches of light into meaningfully structured wholes within the blink of an eye, this process must combine a high combinatorial capacity with a high speed. Aristotle ($\pm 350\text{BC}/1957$) already realized that the eyes are not merely windows to the world, and he predicted that *"In a shorter time, more will be known about the most remote objects, namely the stars, than about the most nearby topic, namely perception"*. Indeed, more than two thousand years later, Gestalt psychology still posed the pivotal question *"Why do things look as they do?"* It also proposed a promising beginning of an answer, however.

The founding fathers of Gestalt psychology, Max Wertheimer (1880–1943), Wolfgang Köhler (1887–1967), and Kurt Koffka (1886–1941), argued that vision involves a complex interaction between stimulus parts, which manifests itself as if there is a competition between various rules of perceptual grouping. They captured this in their motto *"the whole is something else than the sum of its parts"* (Koffka, 1935, p. 176), and they proposed the law of Prägnanz as governing principle. This law expresses the idea that the brain, like any dynamic physical system, tends to settle in relatively stable states. For vision, Koffka (1935, p. 138) formulated this as follows: *"Of several geometrically possible organizations that one will actually occur which possesses the best, the most stable shape"*. This idea pervades much of modern vision research, including this book.

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This book also fits in the research program envisioned by David Marr (1945–1980). Marr (1982/2010) argued that vision research should strive for complementary descriptions of the goal, the method, and the means of the visual system — rather than promoting a description of only one of these aspects as being the whole story. Furthermore, the methodological division of this book into three parts reflects that it promotes a multidisciplinary approach by which theoretical, empirical, and tractability findings contribute equally to a better understanding of the intricate process of perceptual organization.

Within this historical and methodological setting, and complementary to the empirically oriented book by Leeuwenberg and van der Helm (2013), this book uses structural information theory (SIT) as operating base to explore theoretical issues in form and shape perception. SIT began in the 1960s as a classical model of visual pattern classification, and countering criticism in the 1980s, it developed into a modern and competitive theory of perceptual organization.

I am greatly indebted to SIT's founding father Emanuel Leeuwenberg, who gave his unconditional support to all my scientific endeavors. I am also grateful to Rob van Lier for adding crucial insights to SIT by way of an empirically successful model of amodal completion; to Gert van der Vloed, Árpád Csathó, and Matthias Treder for their critical hypotheses-testing work on symmetry perception; and to Erik Weijers and Vinod Unni for deep discussions on, respectively, the elusive concept of information and the also elusive link between cognitive and neural processing. For their scientific endorsement, I thank the members of the former division of Perception at the Radboud University Nijmegen, Arnold Thomassen, Kees Hoede, Ian Gordon, Stephen Palmer, Michael Kubovy, Walter Gerbino, James Pomerantz, and especially Johan Wagemans and Julian Hochberg. For their support in difficult times, I thank Charles de Weert, Paul Eling, Ben Hofstede, Henk Vergunst, Jacqueline Janssen, Luuk de Blois, Bep Waayenberg, and Louis Konickx. For everything, I thank my beloved Senon, our beautiful daughters Fheonna, Laura, and Vera, and our dear families in The Netherlands and Malaysia.

The general research framework of this book is specified in the Prologue, Chapter 1, and the Epilogue. The Prologue gives an overview of methodological preconsiderations; Chapter 1 presents the main ideas within SIT; and the Epilogue combines the results from Chapters 2–6

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into one picture with indications of several implications for vision-related research and application fields. Chapters 2–6 are based on a collection of articles published in *Journal of Mathematical Psychology* (van der Helm & Leeuwenberg, 1991), *Psychological Review* (van der Helm & Leeuwenberg, 1996), *Psychological Bulletin* (van der Helm, 2000), *Proceedings of the National Academy of Sciences USA* (van der Helm, 2004), and *Cognitive Processing* (van der Helm, 2012).

Chapter 2 is a thoroughly revised and updated version of van der Helm's (2000) discussion of the simplicity principle. This principle is a modern information-theoretic translation of the Gestalt law of *Prägnanz*, and holds — within other neuro-cognitive constraints — that vision results in simplest stimulus organizations. An implicit assumption then is that such organizations are sufficiently veridical to guide us through the world. This assumption is sustained in a historical setting, using findings from the mathematical domain of algorithmic information theory (a.k.a. the theory of Kolmogorov complexity).

Chapter 3 is an entirely new version of van der Helm and Leeuwenberg's (1991) formalization of visual regularity. Beginning with evolutionary preconsiderations, it establishes the mathematically unique nature of the hierarchically transparent and holographic regularities (such as symmetry and repetition) that are proposed to be exploited to arrive at simplest perceptual organizations.

Chapter 4 reviews the line of research initiated by van der Helm and Leeuwenberg (1996). It discusses how the formalization in Chapter 3 led to a quantitative model of the detectability of single and combined visual regularities, whether or not perturbed by noise. This model, in turn, formed the basis of a qualitative process model of the detection of visual regularities. Discussed are critical empirical tests of these models, which suggest that the transparent holographic nature of these regularities is indeed pertinent in perception and in daily life.

Chapter 5 expands on van der Helm's (2004) process model of perceptual organization. This model computes simplest hierarchical organizations of strings via a neurally plausible combination of feedforward feature extraction, horizontal feature binding, and recurrent feature selection. Crucially, its binding mechanism allows for transparallel processing by hyperstrings — feasible on classical computers and as powerful as quantum computers promise to be. This does justice to the high combinatorial capacity and speed of perceptual organization.

Chapter 6 updates and expands on van der Helm's (2012) study,

which related representational approaches to connectionism and dynamic systems theory. In the spirit of Marr (1982/2010), these three approaches are argued to be complementary rather than mutually exclusive. Together, they yield a picture of flexible cognitive architecture constituted by hierarchies of transient neural assemblies — dubbed *gnosons* — which signal their presence by synchronization of the neurons involved. This phenomenon of neuronal synchronization is proposed to be a manifestation of transparallel processing as characterized in Chapter 5.

Finally, to put things into perspective, modern scientific research may have replaced intuition by formal models and rigorous experiments to develop and test theories, but theorizing is also a sort of story-telling. In this respect, it fits in the oral tradition which, throughout human history, has given meaning to life by way of stories that connect people to their world (which nowadays includes those models and experiments). Every story highlights only part of the human condition, and every story inevitably changes over time to reflect current beliefs and findings. As for the truthfulness of stories, including scientific theories, I can therefore only quote my father-in-law, traditional story-teller Seman bin Samad (see photo below): *"True? I don't know, but this is the story"*.

Peter A. van der Helm

Seman bin Samad (± 1930 –2008), story-teller of the Jakun at the legendary lake Tasik Chini in West Malaysia. The Jakun belong to the indigenous people called Orang Asli (for more information, see <http://sites.keene.edu/mason/orang-asli-archive>).

