Visual Processing of Shape and Form

Introduction

Goals:

Understand role of shape in everyday human vision, predict performance in shape-based tasks with natural images, and understand how shape processing occurs in the brain.

Scope:

Human visual object perception and grasp, haptic only in the context of vision for grasp.

Focus on: objects (not scences, or 2D patterns (text)

What is shape, form?

Mathematician's view

Computer vision, morphometrics, computer graphics

(Loncaric, 1998) (Bookstein, 1997) (Koenderink, 1990) (Grenander, 1996)
(Foley, van Dam, Feiner, & Hughes, 1990)

Psychologist's view

Shape is not a function of depth

Tied to visual function (see below)

Traditional distinctions?

2D form, 3D shape, "configurational"

(Leyton, 1992; Rock, Schreiber, & Ro, 1994)

Neurophysiologists view

Should match the psychologist's, if not the mathematician's—but does it?

(Treisman, Cavanagh, Fischer, Ramachandran, & Heydt, 1990)

Shape: Computational Theory

Shape in Natural Tasks – "shape-for-X"

Object perception, recognition, shape at different levels of abstraction

Grasp

Keywords: grasp, recognition, attention, local, global

Decision theory & tasks

Characterizing knowledge about shape – "X-from-shape"

Strategy: Understand the "generative model" for shape classes (what is a shape class?)

Generative modeling: Two components

The object: Prior shape regularities

Modeling in 3D

The image: Projected shape regularities and features

Not just geometry! Not necessarily a function of an "object"—e.g. letters.
Modeling in 2D

Shape perception & behavior—"shape-from-X"

Using generative knowledge to do shape through inference

Characterizing knowledge about shape -- Generative models

The causal factors, surface, object, material: Prior shape regularities

How do tasks determine the types of shape representations required?

Recognition

Parameters to be estimated

Intrinsic—translation, size, rotation invariance

Grasp

Parameters to be estimated

(Blake, 1992)

Frame of reference

Shape representation constrained by its availability through image data vision (e.g. geons)

Stochastic

Types of shape representations/models

Metric

Deformable templates, splines

Qualitative

Structural descriptions (2D and 3D)

Shape "representations" What are the natural "structural regularities of shapes?

Generic constraints:

Surface smoothness
Object rigidity
Planarity
Compactness
Symmetry
Polyhedral

(Kontsevich, 1998)

Class-specific regularities

e.g. fonts, script, faces (2D or 3D), polyhedral, trees?…

(e.g. modeled as deformable templates or structural descriptions, in 2D or 3D (e.g. faces)).

Articulation models

Body motions, scissors, facial expressions

Need for statistical models (e.g. trees, etc..)

Knowledge put in prior

Keywords: 2D, 3D, gestalt, contour, surface, symmetry, morphometric, deformable templates,

The image: Projected shape regularities and features

Regularities in the image are produced by regularities in objects + illumination, material + viewpoint. Leads to:

Confounds to full and/or intrinsic geometric information

Viewpoint, occlusion

Because image is determined by more than geometry, inference (see below) is also confounded by:

Illumination, material,

Knowledge put in likelihood

What are the consequences of 3D object geometric regularities in the 2D image? In motion?

Primitive or elementary shapes:

shape index: Koenderink (1990); shape characteristic: (Mamassian, Kersten, & Knill, 1996)

geons: Biederman (1987)

object parts: (Hoffman & Singh, 1997), (Saiki & Hummel, 1998), Rosin (2000)

Singularities of contours: (Siddiqi, Kimia, Tannenbaum, & Zucker, 1999)

Projection invariants:

Non-accidental properties, Lowe.

Form constraint: symmetry, etc.

Perspective invariants: (Pizlo, Rosenfeld, & Weiss, 1997) (Pizlo, 1994; Pizlo & Salachgolyska, 1995)

Need to understand regularities in confounding variable:

Kersten

e.g. stationary light source

Cue integration models

(Landy, Maloney, Johnston, & Young, 1995) (Maloney & Landy, 1989; Uttal, Spillmann, Sturzel, & Sekuler, 2000) (Uttal, Liu, & Kalki, 1996) (Johnston, Cumming, & Landy, 1994) (Young, Landy, & Maloney, 1993) *(Knill, 1998)*

Keywords: cues, shading, edges, image contours, texture, natural image classes (face, scene), cue integration, motion

Machine Learning: Acquiring knowledge about the shapes of objects and the information images have about objects

2D & 3D acquisition

The density estimation modeling problem

(Zhu, 1999)

Loncaric (1998), Koenderink (1998??)Koenderink (1990)

Other papers: David Jacobs, Davi Geiger, Zucker et al. (1999)

Shape perception & behavior

The segmentation problem

Function/task determines the image information (features) required, based on utility, reliability and diagnosticity. So silhouette form is good for distinguishing cats from dogs, but not cats from each other

Psychophysical challenges:

Dealing with the complexity of images

Indirectness of methodology at getting at psychological representations and mechanisms

Behavioristic bias

Task-independent processing (early) “Task-general”, task-neutral.

Shape as an intermediate, task-general representation useful for various tasks. Shape judgments as an end in themselves.

Local image measurements supporting shape

Image edges, texture, disparity,

Computational problems of shape inference

A specific shape parameter can be related to by multiple image measurements→ cue integration

Improved reliability, robustness

(Bülthoff & Mallot, 1988), (Landy et al., 1995)

Other papers: [Nawrot, 1996 #81(Tittle, Norman, Perotti, & Phillips, 1998) (Johnston et al., 1994) (Rogers, Li, & Dannemiller, 1995) (Johnston & Passmore, 1994)

A set of image measurements is a function of more than one shape:

Bayes priors

(Mamassian & Landy, 1998)

A specific image measurement is a function of more than shape

Decision theory/task analysis

(Freeman, 1994),

Bas-relief example (Belhumeur, Kriegman, & Yuille, 1997)

Cooperative computatation

(Adelson, 1999) (Knill & Kersten, 1991) (Bloj, Kersten, & Hurlbert, 1999)

Discounting secondary variables

(Kersten & Schrater, 2000), (Bloj et al., 1999)

Priors and noise

Key paper: (Hogervorst & Eagle, 1998)

Ambiguities in depth cues

Shading: (Mamassian et al., 1996), (Dehaan, Erens, & Noest, 1995)

Shape representation

Local depth v. surface orientation: (Reichel, Todd, & Yilmaz, 1995)

Surface orientation vs. curvature: (Johnston & Passmore, 1994), (Curran & Johnston, 1996)

Invariants: (Pizlo & Salachgolyska, 1995)

Review papers: (Lappin & Craft, 2000)

Other papers: Koenderink, Todd, Rogers

From local to global

Frames of reference

Axes: (Quinlan & Humphreys, 1993), (Driver & Baylis, 1995)

Alignment: (Pani, Jeffres, Shippey, & Schwartz, 1996)

Using generic structural regularities

Surface smoothness, Object rigidity

Compactness, planarity

(Sinha & Adelson, 1993)

Symmetry

(Wagemans, 1995), Tyler, Schrater et al.

honeybees: (Lehrer, 1999)

Glass patterns: (Wilson & Wilkinson, 1998) (Maloney, Mitchison, & Barlow, 1987)

Using object class

(Navon, 1977)

Other papers: (Alais, van der Smagt, van den Berg, & van de Grind, 1998)

How to group: Similarity

In pigeons: (Blough & Blough, 1997)

Grouping by assimilation: (van Lier & Wagemans, 1997; Yin, Kellman, & Shipley, 2000)

Shape-from-X:

"cues, X, are statistics" – (Geiger, Rudra, & Maloney, 1997; Kersten & Schrater, 2000).

Luminance: (Shioiri & Cavanagh, 1992)

Contour vs. texture: (Battelli, Casco, & Sartori, 1997) Elder

Contour closure: (Saarinen & Levi, 1999) Elder

Shadows: (Norman, Dawson, & Raines, 2000) Lappin

Shape from active exploration

: (Vandamme, Oosterhoff, & Vandegrind, 1994), (Hershberger & Misceo, 1996) (Watanabe, Pollick, Koenderink, & Kawato, 1999)

Other papers: (Vandamme & Vandegrind, 1993), (Mamassian & Bülthoff, 1993), (Ballesteros, Millar, & Reales, 1998), (Lakatos & Marks, 1999)

Shape-despite-X: Discounting secondary variables

Viewpoint & illumination: (Todd, Koenderink, vanDoorn, & Kappers, 1996; Todd, Norman, Koenderink, & Kappers, 1996) (Koenderink, vanDoorn, Christou, & Lappin, 1996)

Illumination: (Braje, Kersten, Tarr, & Troje, 1998) (Tarr, Kersten, & Bulthoff, 1998)

Surface reflectance: (Todd, Norman, Koenderink, & Kappers, 1997)?

Image orientation: (Rock et al., 1994)

Lighting model: (Johnston & Curran, 1996)

Motion: (Stone, 1999)

Shape for recognition

Part shape for recognition

Convexities/concavities: (Hulleman, Winkel, & Boselie, 2000)

(Bülthoff, Edelman, & Tarr, 1995) (Biederman, 1987))

Computer models:

Bayesian by parts: (Nair & Aggarwal, 2000) (Zhu & Yuille, 1996) (Bolle & Cooper, 1984) Pentland.

(Hummel & Stankiewicz, 1996) (Hummel & Stankiewicz, 1998)

Amodal completion: (Tse, 1999a, 1999b)

Shape for grasp

Issues: goal-directed action, frame for reference

(Santello & Soechting, 1998), Goodale??

Curvature vs. shape: Pont et al. (1998)

Interaction between perception and action

Haptic vs. visual: (Kappers, Koenderink, & Oudenaarden, 1997)

Depth cues: (Ernst, Banks, & Bulthoff, 2000) (Aglioti, DeSouza, & Goodale, 1995)

Motion: (Wohlschlager, 2000)

Learning

In pigeons: Kirkpatrick-Steger et al. (2000)??

Localization of shape: (Sigman & Gilbert, 2000)

(Sinha & Poggio, 1996), (Shams & von der Malsburg, 1999), Brady & Kersten

Review papers: Schyns et al. (1998)??

Perceptual development

Recognition: (Quinn, Brown, & Streppa, 1997) (Wilcox, 1999)

Good form: (Johnson, 2000)

Action: (Misceo, Hershberger, & Mancini, 1999)

Shape perception and the brain

Early measurements & shape

Review (Treisman et al., 1990)

V1 & curvature

(Dobbins, Zucker, & Cynader, 1987)

Illusory shapes

(von der Heydt, Peterhans, & Baumgartner, 1984) (Peterhans & von der Heydt, 1989; Peterhans, von der Heydt, & Baumgartner, 1986; von der Heydt & Peterhans, 1989) (Heitger, Rosenthaler, Von der Heydt, Peterhans, & Kübler, 1992)

Illusory contours: [(Dresp, 1997) Brady & Kersten

Illusory volumes: (Carman & Welch, 1992; Matthews & Welch, 1997), (Tse, 1998)

Recognition

Visual pathways:

Shape vs. location: Jeannerod (1981) (Jeannerod, 1981)

Shape vs. color: Gegenfurtner et al.??, (McClurkin, Zarbock, & Optican, 1996)

Shape vs. surface material: (Roland, O'Sullivan, & Kawashima, 1998)

Shape vs. motion: (Cowey & Vaina, 2000)

Shape vs figure-ground segregation: (Davidoff & Warrington, 1993)

Neuroimaging for recognition (ERP, PET, fMRI):

Issues: localization of shape representation and processing

(Kourtzi & Kanwisher, 2000), (Medola, 1999)

Other papers: (Grill-Spector et al., 1998), (Ito, Kuwabara, Sugata, Suzuki, & Kawai, 1998; Ito & Sugata, 1995; Ito, Sugata, & Kuwabara, 1997; Ito, Sugata, Kuwabara, Wu, & Kojima, 1999), (Beason-Held et al., 1998), (Larsson et al., 1999), (Evans, 2000)

Neurophysiology for recognition:

Shape from stereo: (von der Heydt, Zhou, & Friedman, 2000)

Occluded shapes: (Kovacs, Vogels, & Orban, 1995)

Neuropsychology for recognition:

Issues: visual agnosia, blindsight, neglect

(Humphreys, 2000), (Cowey & Vaina, 2000)

Papers: (Marcel, 1998), (Merigan, Freeman, & Meyers, 1997), (Farah & Feinberg, 1997)

Review papers: (Heider, 2000)

Neural neworks:

Grossberg

Action

Review: (Jeannerod, Arbib, Rizzolatti, & Sakata, 1995)

Neuroimaging for action (ERP, PET, fMRI):

Shape by touch: (Bodegard et al., 2000)

Goodale?? (Faillenot, Decety, & Jeannerod, 1999)

Neurophysiology for action:

Issues: frames of reference, population coding

Georgopoulos??

Review papers: (Colby & Goldberg, 1999)

Neuropsychology for action:

Issues: double dissociations between visual agnosia and apraxia, Balint syndrome (Goodale & Milner, 1992) (DF), (Humphrey, Symons, Herbert, & Goodale, 1996) (Milner, 1974)

Review papers: (Jeannerod et al., 1995)

References – Alphabetical

Adelson, E. H. (1999). Lightness Perception and Lightness Illusions. In M. S. M. Gazzaniga (Ed.), *The New Cognitive Neurosciences* (pp. 339-351). Cambridge, MA: MIT Press.

Aglioti, S., DeSouza, J. F. X., & Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. *Current Biology, 5*(6), 679-685.

Alais, D., van der Smagt, M. J., van den Berg, A. V., & van de Grind, W. A. (1998). Local and global factors affecting the coherent motion of gratings presented in multiple apertures. *Vision Research, 38*(11), 1581-1591.

Ballesteros, S., Millar, S., & Reales, J. M. (1998). Symmetry in haptic and in visual shape perception. *Perception & Psychophysics, 60*(3), 389-404.

Battelli, L., Casco, C., & Sartori, G. (1997). Dissociation between contour-based and texture-based shape perception: A single case study. *Visual Cognition, 4*(3), 275-310.

Beason-Held, L. L., Purpura, K. P., Van Meter, J. W., Azari, N. P., Mangot, D. J., Optican, L. M., Mentis, M. J., Alexander, G. E., Grady, C. L., Horwitz, B., Rapoport, S. I., & Schapiro, M. B. (1998). PET reveals occipitotemporal pathway activation during elementary form perception in humans. *Visual Neuroscience, 15*(3), 503-510.

Belhumeur, P. N., Kriegman, D. J., & Yuille, A. (1997). *The Bas-Relief Ambiguity.* Paper presented at the IEEE Conf. on Computer Vision and Pattern Recognition.

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review, 94*, 115-147.

Blake, A. (1992). Computational modelling of hand-eye coordination. *Philosophical Transactions Royal Society Lond, 337*, 3510360.

Bloj, M. G., Kersten, D., & Hurlbert, A. C. (1999). Perception of three-dimensional shape influences colour perception through mutual illumination. *Nature, 402*(6764), 877-879.

Blough, D. S., & Blough, P. M. (1997). Form perception and attention in pigeons. *Animal Learning & Behavior, 25*(1), 1-20.

Bodegard, A., Ledberg, A., Geyer, S., Naito, E., Zilles, K., & Roland, P. E. (2000). Object shape differences reflected by somatosensory cortical activation in human. *Journal of Neuroscience*, *20*(1), RC51-U58.

Bolle, R. M., & Cooper, D. B. (1984). Bayesian recognition of local 3- D shape by approximating image intensity functions with quadric polynomials. *IEEE Trans. Patt. Anal. and Machine Intell.,PAMI-6*, 418-429.

Bookstein, F. L. (1997). Shape and the information in medical images: A decade of the morphometric synthesis. *Computer Vision and Image Understanding, 66*(2), 97-118.

Braje, W. L., Kersten, D., Tarr, M. J., & Troje, N. F. (1998). Illumination effects in face recognition. *Psychobiology, 26*(4), 371-380.

Bülthoff, H. H., Edelman, S. Y., & Tarr, M. J. (1995). How are three-dimensional objects represented in the brain? *Cerebral Cortex, 5*(3), 247-260.

Bülthoff, H. H., & Mallot, H. A. (1988). Integration of depth modules: stereo and shading. *Journal of the Optical Society of America, A, 5*(10), 1749-1758.

Carman, G. J., & Welch, L. (1992). Three-dimensional illusory contours and surfaces. *Nature, 360*, 585-587.

Colby, & Goldberg. (1999).

Cowey, A., & Vaina, L. M. (2000). Blindness to form from motion despite intact static form perception and motion detection. *Neuropsychologia, 38*(5), 566-578.

Curran, W., & Johnston, A. (1996). Three-dimensional curvature contrast - Geometric or brightness illusion? *Vision Research, 36*(22), 3641-3653.
Davidoff, J., & Warrington, E. K. (1993). A Dissociation of Shape-Discrimination and Figure Ground Perception in a Patient with Normal Acuity. *Neuropsychologia, 31*(1), 83-93.
Dehaan, E., Erens, R. G. F., & Noest, A. J. (1995). Shape from Shaded Random Surfaces. *Vision Research, 35*(21), 2985-3001.
Dobbins, A., Zucker, S. W., & Cynader, M. S. (1987). Endstopped neurons in the visual cortex as a substrate for calculating curvature., *329*(6138), 438-441.
Dresp, B. (1997). On "illusory" contours and their functional significance. *Cahiers De Psychologie Cognitive-Current Psychology of Cognition, 16*(4), 489-518.
Driver, J., & Baylis, G. C. (1995). Tilted Letters and Tilted Words - a Possible Role for Principal Axes in Visual Word Recognition. *Memory & Cognition, 23*(5), 560-568.
Ernst, M. O., Banks, M. S., & Bulthoff, H. H. (2000). Touch can change visual slant perception. *Nat Neurosci, 3*(1), 69-73.
Evans. (2000).
Faillenot, I., Decety, J., & Jeannerod, M. (1999). Human brain activity related to the perception of spatial features of objects. *Neuroimage, 10*(2), 114-124.
Farah, M. J., & Feinberg, T. E. (1997). Consciousness of perception after brain damage. *Seminars in Neurology, 17*(2), 145-152.
Foley, J., van Dam, A., Feiner, S., & Hughes, J. (1990). *Computer Graphics Principles and Practice* (2nd ed.). Reading, Massachusetts: Addison-Wesley Publishing Company.
Freeman, W. T. (1994). The generic viewpoint assumption in a framework for visual perception. *Nature, 368*(7 April 1994), 542-545.
Geiger, D., Rudra, A., & Maloney, L. (1997). *Features as Sufficient Statistics.* Paper presented at the Neural Information Processing Systems, Denver, Colorado.
Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neuroscience, 15*(1), 20-25.
Grenander, U. (1996). *Elements of pattern theory*. Baltimore: Johns Hopkins University Press.
Grill-Spector, K., Kushnir, T., Hendler, T., Edelman, S., Itzchak, Y., & Malach, R. (1998). A sequence of object-processing stages revealed by fMRI in the human occipital lobe. *Human Brain Mapping, 6*(4), 316-328.
Heider, B. (2000). Visual form agnosia: Neural mechanisms and anatomical foundations. *Neurocase, 6*(1), 1-12.
Heitger, F., Rosenthaler, L., Von der Heydt, R., Peterhans, E., & Kübler, O. (1992). Simulation of neural contour mechanisms: From simple to end-stopped cells. *Vision Research, 32*, 963-981.
Hershberger, W. A., & Misceo, G. F. (1996). Touch dominates haptic estimates of discordant visual-haptic size. *Perception & Psychophysics, 58*(7), 1124-1132.
Hoffman, D. D., & Singh, M. (1997). Salience of visual parts. *Cognition, 63*(1), 29-78.
Hogervorst, M. A., & Eagle, R. A. (1998). Biases in three-dimensional structure-from-motion arise from noise in the early visual system. *Proceedings of the Royal Society of London Series B-Biological Sciences, 265*(1406), 1587-1593.
Hulleman, J., Winkel, W. T., & Boselie, F. (2000). Concavities as basic features in visual search: Evidence from search asymmetries. *Perception & Psychophysics, 62*(1), 162-174.

Hummel, J. E., & Stankiewicz, B. J. (1996). Categorical relations in shape perception. *Spatial Vision, 10*(3), 201-236.

Hummel, J. E., & Stankiewicz, B. J. (1998). Two roles for attention in shape perception: A structural description model of visual scrutiny. *Visual Cognition, 5*(1-2), 49-79.

Humphrey, G. K., Symons, L. A., Herbert, A. M., & Goodale, M. A. (1996). A neurological dissociation between shape from shading and shape from edges. *Behavioural Brain Research, 76*(1-2), 117-125.

Humphreys, G. W. (2000).

Ito, M., Kuwabara, H., Sugata, T., Suzuki, K., & Kawai, Y. (1998). Visual evoked potentials to the geometric forms in the randomized presentation. *Japanese Psychological Research, 40*(2), 111-116.

Ito, M., & Sugata, T. (1995). Visual evoked potentials to geometric forms. *Japanese Psychological Research, 37*(4), 221-228.

Ito, M., Sugata, T., & Kuwabara, H. (1997). Visual evoked potentials to geometric forms: Effects of spatial orientation. *Japanese Psychological Research, 39*(4), 339-344.

Ito, M., Sugata, T., Kuwabara, H., Wu, C. J., & Kojima, K. (1999). Effects of angularity of the figures with sharp and round corners on visual evoked potentials. *Japanese Psychological Research, 41*(2), 91-101.

Jeannerod, M. (1981). Intersegmental coordination during reaching at natural visual objects. In J. Long & A. Baddeley (Eds.), *Attention and Performance* (Vol. IX, pp. 153-168). Hillsdale: Erlbaum.

Jeannerod, M., Arbib, M. A., Rizzolatti, G., & Sakata, H. (1995). Grasping objects: the cortical Mechanisms of visuomotor transformation. *Trends in Neurosciences, Review, 18, No. 7*(Trends in Neurosciences, Cambridge, UK), 314-320.

Johnson. (2000).

Johnston, A., & Curran, W. (1996). Investigating shape-from-shading illusions using solid objects. *Vision Research, 36*(18), 2827-2835.

Johnston, A., & Passmore, P. J. (1994). Independent Encoding of Surface Orientation and Surface Curvature. *Vision Research, 34*(22), 3005-3012.

Johnston, E. B., Cumming, B. G., & Landy, M. S. (1994). Integration of Stereopsis and Motion Shape Cues. *Vision Research, 34*(17), 2259-2275.

Kappers, A. M. L., Koenderink, J. J., & Oudenaarden, G. (1997). Large scale differences between haptic and visual judgments of curvature. *Perception, 26*(3), 313-320.

Kersten, D., & Schrater, P. W. (2000). Pattern Inference Theory: A Probabilistic Approach to Vision. In R. Mausfeld & D. Heyer (Eds.), *Perception and the Physical World*. Chichester: John Wiley & Sons, Ltd.

Knill, D. C. (1998). Discrimination of planar surface slant from texture: human and ideal observers compared. *Vision Research, 38*(11), 1683-1711.

Knill, D. C., & Kersten, D. (1991). Apparent surface curvature affects lightness perception. *Nature, 351*, 228-230.

Koenderink, J. J. (1990). *Solid Shape*. Cambridge, MA: MIT Press.

Koenderink, J. J., vanDoorn, A. J., Christou, C., & Lappin, J. S. (1996). Shape constancy in pictorial relief. *Perception, 25*(2), 155-164.

Kontsevich, L. L. (1998). Defaults in stereoscopic and kinetic depth perception. *Proceedings of the Royal Society of London Series B-Biological Sciences, 265*(1406), 1615-1621.

Kourtzi, Z., & Kanwisher, N. (2000). Cortical regions involved in perceiving object shape. *Journal of Neuroscience, 20*(9), 3310-3318.

Kovacs, G., Vogels, R., & Orban, G. A. (1995). Selectivity of Macaque Inferior Temporal Neurons for Partially Occluded Shapes. *Journal of Neuroscience, 15*(3), 1984-1997.

Lakatos, S., & Marks, L. E. (1999). Haptic form perception: Relative salience of local and global features. *Perception & Psychophysics, 61*(5), 895-908.

Landy, M. S., Maloney, L. T., Johnston, E. B., & Young, M. J. (1995). Measurement and modeling of depth cue combination: In defense of weak fusion. *Vision Research, 35*, 389-412.

Lappin, J. S., & Craft, W. D. (2000). Foundations of spatial vision: From retinal images to perceived shapes. *Psychological Review, 107*(1), 6-38.

Larsson, J., Amunts, K., Gulyas, B., Malikovic, A., Zilles, K., & Roland, P. E. (1999). Neuronal correlates of real and illusory contour perception: functional anatomy with PET. *European Journal of Neuroscience, 11*(11), 4024-4036.

Lehrer, M. (1999). Shape perception in the honeybee: Symmetry as a global framework. *International Journal of Plant Sciences, 160*(6), S51-S65.

Leyton, M. (1992). *Symmetry, Causality, Mind*. Cambridge, Massachusetts: The MIT Press.

Loncaric, S. (1998). A survey of shape analysis techniques. *Pattern Recognition, 31*(8), 983-1001.

Maloney, L. T., & Landy, M. S. (1989). *A statistical framework for robust fusion of depth information.* Paper presented at the SPIE Visual Communications and Image Processing.

Maloney, R. K., Mitchison, G. J., & Barlow, H. B. (1987). The limit to the detection of Glass patterns in the presence of noise. *Journal of the Optical Society of America, A 4*, 2336-2341.

Mamassian, P., & Bülthoff, H. H. (1993).

Mamassian, P., Kersten, D., & Knill, D. C. (1996). Categorical local-shape perception. *Perception, 25*(1), 95-107.

Mamassian, P., & Landy, M. S. (1998). Observer biases in the 3D interpretation of line drawings. *Vision Research, 38*(18), 2817-2832.

Marcel, A. J. (1998). Blindsight and shape perception: deficit of visual consciousness or of visual function? *Brain, 121*, 1565-1588.

Matthews, N., & Welch, L. (1997). The effect of inducer polarity and contrast on the perception of illusory figures. *Perception, 26*(11), 1431-1443.

McClurkin, J. W., Zarbock, J. A., & Optican, L. M. (1996). Primate striate and prestriate cortical neurons during discrimination .2. Separable temporal codes for color and pattern. *Journal of Neurophysiology, 75*(1), 496-507.

Medola. (1999).

Merigan, W., Freeman, A., & Meyers, S. P. (1997). Parallel processing streams in human visual cortex. *Neuroreport, 8*(18), 3985-3991.

Milner, P. M. (1974). A Model For Visual Shape Recognition. *Psychological Review, 81*(6), 521-535.

Misceo, G. F., Hershberger, W. A., & Mancini, R. L. (1999). Haptic estimates of discordant visual-haptic size vary developmentally. *Perception & Psychophysics, 61*(4), 608-614.

Nair, D., & Aggarwal, J. K. (2000). Bayesian recognition of targets by parts in second generation forward looking infrared images. *Image and Vision Computing, 18*(10), 849-864.

Navon, D. (1977). Forest before the trees: The precedence of global features in visual perception. *Cognitive Psychology, 9*, 353-383.
Norman, J. F., Dawson, T. E., & Raines, S. R. (2000). The perception and recognition of natural object shape from deforming and static shadows. *Perception, 29*(2), 135-148.
Pani, J. R., Jeffres, J. A., Shippey, G. T., & Schwartz, K. J. (1996). Imagining projective transformations: Aligned orientations in spatial organization. *Cognitive Psychology, 31*(2), 125-167.
Peterhans, E., & von der Heydt, R. (1989). Mechanisms of contour perception in monkey visual cortex. II. Contours bridging gaps. *Journal of Neuroscience, 9*(5), 1749-1763.
Peterhans, E., von der Heydt, R., & Baumgartner, G. (1986). Neuronal responses to illusory contours stimuli reveal stages of visual cortical processing. In J. Pettigrew & K. J. Sanderson & W. R. Levick (Eds.), *Visual Neuroscience* (pp. 343-351). Cambridge, England: Cambridge University Press.
Pizlo, Z. (1994). A Theory of Shape Constancy Based on Perspective Invariants. *Vision Research, 34*(12), 1637-1658.
Pizlo, Z., Rosenfeld, A., & Weiss, I. (1997). The geometry of visual space: About the incompatibility between science and mathematics. *Computer Vision and Image Understanding, 65*(3), 425-433.
Pizlo, Z., & Salachgolyska, M. (1995). 3-D Shape Perception. *Perception & Psychophysics, 57*(5), 692-714.
Quinlan, P. T., & Humphreys, G. W. (1993). Perceptual Frames of Reference and 2-Dimensional Shape- Recognition - Further Examination of Internal Axes. *Perception, 22*(11), 1343-1364.
Quinn, P. C., Brown, C. R., & Streppa, M. L. (1997). Perceptual organization of complex visual configurations by young infants. *Infant Behavior & Development, 20*(1), 35-46.
Reichel, F. D., Todd, J. T., & Yilmaz, E. (1995). Visual-Discrimination of Local Surface Depth and Orientation. *Perception & Psychophysics, 57*(8), 1233-1240.
Rock, I., Schreiber, C., & Ro, T. (1994). The Dependence of 2-Dimensional Shape Perception on Orientation. *Perception, 23*(12), 1409-1426.
Rogers, S., Li, H. C., & Dannemiller, J. L. (1995). Scaling Not Disparity Curvature, Explains 3-D Shape Perception. *Investigative Ophthalmology & Visual Science, 36*(4), S185-S185.
Roland, P. E., O'Sullivan, B., & Kawashima, R. (1998). Shape and roughness activate different somatosensory areas in the human brain. *Proceedings of the National Academy of Sciences of the United States of America, 95*(6), 3295-3300.
Saarinen, J., & Levi, D. M. (1999). The effect of contour closure on shape perception. *Spatial Vision, 12*(2), 227-238.
Saiki, J., & Hummel, J. E. (1998). Connectedness and the integration of parts with relations in shape perception. *Journal of Experimental Psychology-Human Perception and Performance, 24*(1), 227-251.
Santello, M., & Soechting, J. F. (1998). Gradual molding of the hand to object contours. *J Neurophysiol, 79*(3), 1307-1320.
Shams, L., & von der Malsburg, C. (1999). Are object shape primitives learnable? *Neurocomputing, 26-7*, 855-863.
Shioiri, S., & Cavanagh, P. (1992). Achromatic Form Perception Is Based on Luminance, Not Brightness. *Journal of the Optical Society of America a-Optics Image Science and Vision, 9*(10), 1672-1681.

Siddiqi, K., Kimia, B. B., Tannenbaum, A., & Zucker, S. W. (1999). Shapes, shocks and wiggles. *Image and Vision Computing, 17*(5-6), 365-373.

Sigman, & Gilbert. (2000).

Sinha, P., & Adelson, E. (1993). *Recovering reflectance and illumination in a world of painted polyhedra.* Paper presented at the Proceedings of Fourth International Conference on Computer Vision, Berlin.

Sinha, P., & Poggio, T. (1996). Role of learning in three-dimensional form perception. *Nature, 384*(6608), 460-463.

Stone, J. V. (1999). Object recognition: view-specificity and motion-specificity. *Vision Research, 39*(24), 4032-4044.

Tarr, M. J., Kersten, D., & Bulthoff, H. H. (1998). Why the visual recognition system might encode the effects of illumination. *Vision Res, 38*(15-16), 2259-2275.

Tittle, J. S., Norman, J. F., Perotti, V. J., & Phillips, F. (1998). The perception of scale-dependent and scale-independent surface structure from binocular disparity, texture, and shading. *Perception, 27*(2), 147-166.

Todd, J. T., Koenderink, J. J., vanDoorn, A. J., & Kappers, A. M. L. (1996). Effects of changing viewing conditions on the perceived structure of smoothly curved surfaces. *Journal of Experimental Psychology-Human Perception and Performance, 22*(3), 695-706.

Todd, J. T., Norman, J. F., Koenderink, J. J., & Kappers, A. M. L. (1996). Effects of texture, illumination and surface reflectance on stereoscopic shape perception. *Investigative Ophthalmology & Visual Science, 37*(3), 4282-4282.

Todd, J. T., Norman, J. F., Koenderink, J. J., & Kappers, A. M. L. (1997). Effects of texture, illumination, and surface reflectance on stereoscopic shape perception. *Perception, 26*(7), 807-822.

Treisman, A., Cavanagh, P., Fischer, B., Ramachandran, V. S., & Heydt, R. V. D. (1990). Form Perception and Attention - Striate Cortex and Beyond. *Visual Perception: The Neurophysiological Foundations*, 273-316.

Tse, P. U. (1998). Illusory volumes from conformation. *Perception, 27*(8), 977-992.

Tse, P. U. (1999a). Complete mergeability and amodal completion. *Acta Psychologica, 102*(2-3), 165-201.

Tse, P. U. (1999b). Volume completion. *Cognitive Psychology, 39*(1), 37-68.

Uttal, W. R., Liu, N., & Kalki, J. (1996). An integrated computational model of three-dimensional vision. *Spatial Vision, 9*(4), 393-422.

Uttal, W. R., Spillmann, L., Sturzel, F., & Sekuler, A. B. (2000). Motion and shape in common fate. *Vision Research, 40*(3), 301-310.

van Lier, R., & Wagemans, J. (1997). Perceptual grouping measured by color assimilation: Regularity versus proximity. *Acta Psychologica, 97*(1), 37-70.

Vandamme, W. J. M., Oosterhoff, F. H., & Vandegrind, W. A. (1994). Discrimination of 3-D Shape and 3-D Curvature from Motion in Active Vision. *Perception & Psychophysics, 55*(3), 340-349.

Vandamme, W. J. M., & Vandegrind, W. A. (1993). Active Vision and the Identification of 3-Dimensional Shape. *Vision Research, 33*(11), 1581-1587.

von der Heydt, R., & Peterhans, E. (1989). Mechanisms of contour perception in monkey visual cortex. I. Lines of pattern discontinuity. *Journal of Neuroscience, 9*, 1731-1748.

von der Heydt, R., Peterhans, E., & Baumgartner, G. (1984). Illusory contours and cortical neuron responses. *Science, 224*, 1260-1262.
von der Heydt, R., Zhou, H., & Friedman, H. S. (2000). Representation of stereoscopic edges in monkey visual cortex. *Vision Research, 40*(15), 1955-1967.
Wagemans, J. (1995). Detection of Visual Symmetries. *Spatial Vision, 9*(1), 9-32.
Watanabe, H., Pollick, F. E., Koenderink, J. J., & Kawato, M. (1999). Using motor tasks to quantitatively judge 3-D surface curvatures. *Perception & Psychophysics, 61*(6), 1116-1139.
Wilcox, T. (1999). Object individuation: infants' use of shape, size, pattern, and color. *Cognition, 72*(2), 125-166.
Wilson, H. R., & Wilkinson, F. (1998). Detection of global structure in Glass patterns: implications for form vision. *Vision Research, 38*(19), 2933-2947.
Wohlschlager. (2000).
Yin, C., Kellman, P. J., & Shipley, T. F. (2000). Surface integration influences depth discrimination. *Vision Research, 40*(15), 1969-1978.
Young, M. J., Landy, M. S., & Maloney, L. T. (1993). A Perturbation Analysis of Depth Perception from Combinations of Texture and Motion Cues. *Vision Research, 33*(No. 18), 2685-2696.
Zhu, S. C. (1999). Embedding Gestalt Laws in Markov Random Fields. *IEEE Trans. Pattern Analysis and Machine Intelligence., 21*(11).
Zhu, S. C., & Yuille, A. L. (1996). A Flexible Object Recognition and Modelling System. *International Journal of Computer*
Vision, 20(3), 187-212.