THE INVERSE-OPTICS PROBLEM, A DILEMMA OR AN OPPORTUNITY?

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What in an "Inverse Problem"?

- A "forward" problem starts with the causes and then calculates the results.
- An "inverse" problem starts with the results and then calculates the causes.
- Inverse problems give us insights into parameters that we cannot directly observe.
- Applications in fields of: optics, radar, acoustics, communication theory, signal processing, medical imaging, computer vision, geophysics, oceanography, astronomy, remote sensing, natural language processing, machine learning and nondestructive testing

In "optics"

- Refers to the fundamentally ambiguous mapping between sources of retinal stimulation and the perception of what is seen.
- For any given projection on the retina, there are an infinite number of pairings of:
  - *Object size*
  - *Orientation*
  - *Distance*
  - *Color*
  - *Brightness*
  - *Etc.*

References

Understanding vision in wholly empirical terms

Dale Purves[a,1], William T. Wojtach[b], and R. Beau Lotto[c]

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The Inverse-Optics Problem

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Continuing from Chapter 6: Let There Be Light!

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On the Inverse Problem of Binocular 3D Motion Perception

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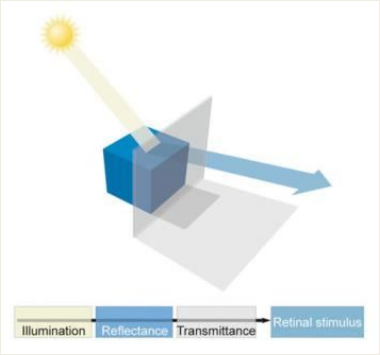
The problem.

- We perceive objects by constructing **spatial analogies** of them and experiencing those analogies, which we come to believe to be the objects themselves, perceived out where they lie beyond the sensory surface.
- The primary function of visual perception is the construction of this volumetric spatial interpretation of objects and surfaces in the world that are most likely to have been responsible for the visual stimulus.
- Because the visual system cannot access the physical world by means of retinal light patterns as such, what we see cannot and does not represent the actual properties of objects or images.
- The phenomenology of visual perceptions can be explained, however, in terms of **empirical** associations that link images whose meanings are inherently undetermined to their behavioral significance.

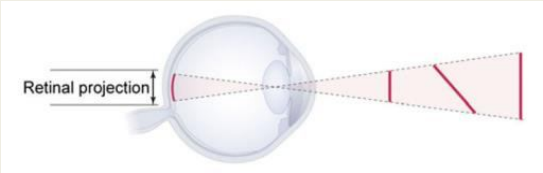
- Light stimuli cannot specify the objects and conditions in the world that caused them.
- Our perceptions result from reinforcing those patterns of stimuli and performances which were "ordered". (Goldstein use of the term)
- Our current behaviors flow from the "behavioral significance" of our prior experiences and not from an analysis of stimulus features in the present.

- "Complexity" in our environment leads to biases in the types of stimuli which we experience, which is limiting in some ways and can lead to "Simplexity". (Berthozian use of the term)
- We modify our connectivity based on the **frequency of occurrence** of targets and contexts to deal with the "inverse problem."
- This leads to the emergence of **useful visually guided behaviors**: operationally determined perceptions that promote behaviors that worked in the past and are thus likely to work in response to current retinal stimuli.

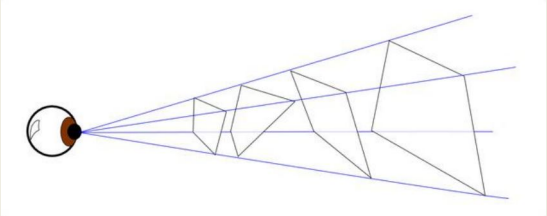
The Retinal Stimulus



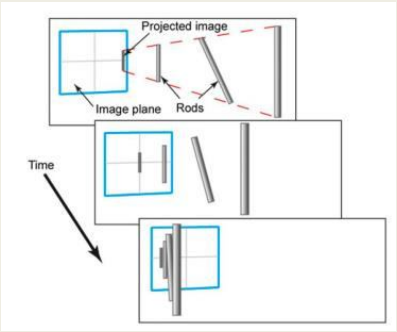
The Projection Problem

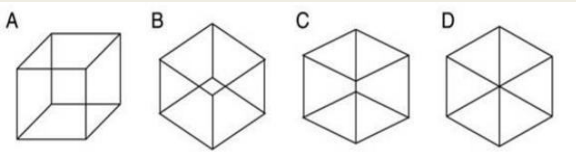


The Projection Problem



Speed and Direction of Movement



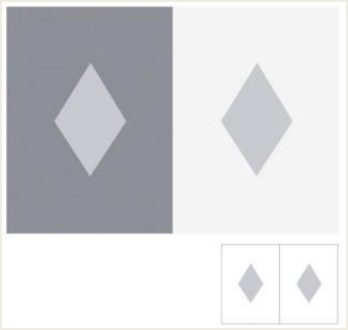


- 2-D or 3-D?
- Ambiguous cases can be observed to flip bistably between two states
- The visual system has constructed both alternatives, and is weighing them against each other in real-time to see which is the **simpler** interpretation.

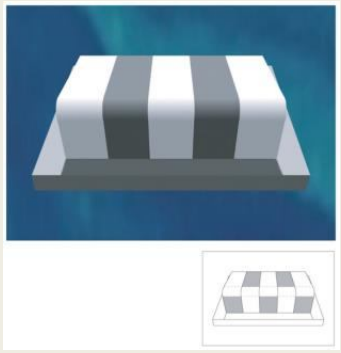
The Wholly Empirical Theory - an experiment takes shape

- Hypothesis: A person's perceptions should be predictable, based on the **frequency of occurrence** of different targets and contexts in visual stimuli generated in nature.
- The better the match the more likely is that organism to survive, favoring systems which evolve these capacities.
- Experience-dependent refinements of connectivity during postnatal development and adult life would allow individuals a higher degree of survivability than genetic solutions alone.

"Lightness" and "Brightness"



"Lightness" and "Brightness"



- Because the empirical scales associated with various surrounds can be quite different, the same target luminance value can have very different rankings when embedded in different contexts and thus can generate quite different perceptions of lightness or brightness.
- "Visual illusion" is incorrect; rather, the perceptions that arise are simply the signature of how the visual brain generates all subjective responses to luminance.

How Does This Develop?

- Natural selection
- Activity-dependent neural plasticity
  - *Feedback from the success or failure of ensuing behaviors is essential to complete the biological loop.*

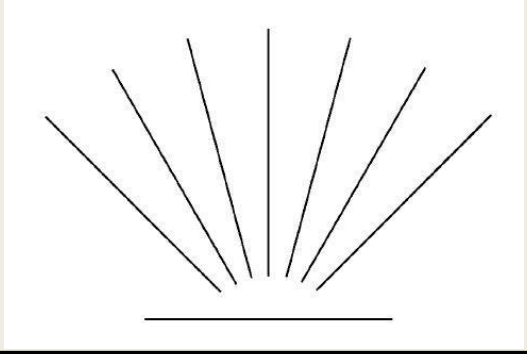
Form

- Form emerges from inextricable intertwining of characteristics of the location and arrangement of the objects in space; size, distance and orientation.

Some Experimentation

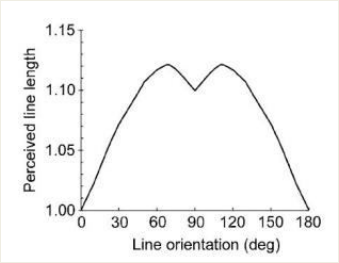
- Created a database of laser range scanning of natural scenes.
- Data used to predict the geometries that people should see if vision is empirically determined.
- **Hypothesis**: In the absence of other contextual information, a line drawn on a piece of paper or computer screen would be expected to correspond more or less directly to the length of the line projected onto the retina.

Line Length Perception
What do you see?



Line Length Perception

- Vertical lines look 10–15% longer than horizontal lines.
- The perception of line length varies continuously as a function of orientation, with the maximum apparent length being elicited by a line stimulus oriented about 30° from vertical.



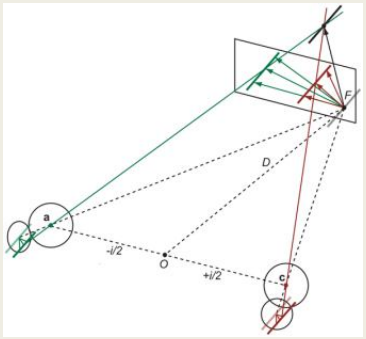
Why?
Natural Scene Analysis

- For lines near vertical, a greater number of shorter than longer projected lines have occurred compared with horizontal line projections of the same length.

What about movement in 3D space?

- The representation of the three-dimensional (3D) external world from two-dimensional (2D) retinal input is a fundamental problem that the visual system has to solve.
- This is true for static and dynamic scenes.
- In 3D scenes with movement seen binocularly the problems mentioned before become almost overwhelming to compute.

Aperture problems of 3D motion with projections



Underlying Physiology

- Any physiologically plausible solution to the inverse 3D motion problem has to rely on binocular sampling of local spatio-temporal information.
- Three cell types available to assist:
  - *Simple and complex motion detecting cells*
  - *Binocular disparity cells sampled over time*
  - *Joint motion and disparity detecting cells*
- Three corresponding theories:
  - *Interocular Velocity Difference (IOVD)*
  - *Changing Disparity Over Time (CDOT)*
  - *Joint Encoding of Motion and Disparity (JEMD)*

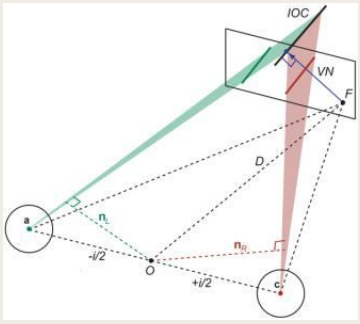
Key Questions

- Does the binocular motion system prefer slow 3D motion or averaged 2D motion?
- Does the system solve stereo correspondence before establishing binocular velocity constraints or does it average 2D velocity constraints from the left and right eye before it solves stereo correspondence?

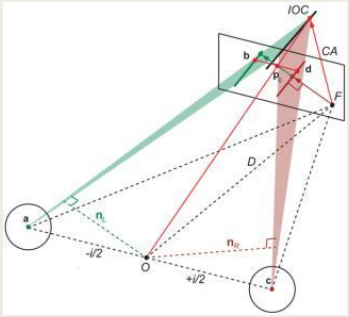
Two Complementary Systems

- Vector Normal - Velocity constraints in the left and right eye provide velocity constraint planes in 3D velocity space.
- Cyclopean Average - If the motion system computes slow 2D motion independently in the left and right eye then the cyclopean average provides an alternative velocity constraint

VN as a default strategy for local 3D motion perception



CA as a default strategy for local 3D motion perception



3D Movement Summary

- It seems likely that the visual system exploits many cues to make this difficult inference as reliable and veridical as possible and the diverse set of effective local and global cues in psychophysical studies already points at late integration within the visual processing hierarchy.
- "More specifically, we suggest that binocular 3D motion perception may be based on parallel motion and depth processing."

Dilemma

- It seems like you can't from here to there and that we should never be able to get from here to there.
- Do we keep working to make more and more complex theories which will eventually give us THE road map for how to dissect what is in the stimulus which will give us THE answer of what we should perceive?
- Or…

Opportunities

- Does this all support our views that we are dealing with people and their cumulative life experiences and that most of what we are dealing with are either:
  - *An overall reduced amount of experience?*
  - *An overall reduced intensity of those experiences?*
  - *Something which has thwarted the person's opportunity to have benefitted from those life experiences?*

The role of the optometrist who practices from the behavioral model

- This frames the majority of what we do as being developmental in nature.
  - *History and diagnostics help us gain insight into the RESULTS which have been derived from the person's cumulative life experiences to date which*
  - *Sets the stage for us to provide our patients with the opportunities to have the necessary meaningful experiences to become more complete and more efficient.*

Thank you. Questions?

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