Psychophysics 2: Noise

- ideal observers  e.g. contrast sensitivity
- image motion
- surface slant
- binocular disparity  (not covered)

Thursday,  Oct. 29,  2015
"Psychophysics": (loose definition)

the study of mappings from physical variables to perceptual variables (measured by behavior)

The stimulus is characterized by "independent variables" that the experimenter manipulates (e.g., luminance contrast, binocular disparity, motion, etc).

How does "noise" in the stimulus variables affect the response?
In the examples last lecture, we were implicitly assuming that the variability in the response was due to processing limitations (e.g. limited sizes of receptive fields of cells in brain). Today we will consider uncertainty in the stimulus itself.
Recall image contrast from last lecture

.... but now add noise

noise present

noise not
\[ I(x, y) = I_0 + \Delta I \cdot \cos \left( \frac{2\pi}{N} k_0 x \right) + n(x, y) \]

Suppose one image has signal and the other doesn't.

How would an ideal observer decide which of two images has the "signal"?
Recall white noise (lecture 7)

white noise signal with mean 0, $\sigma_n = 1.036$

$\hat{n}(x)$

power spectrum (up to Nyquist frequency)

$|\hat{n}(k)|^2$
\[ I(x,y) = I_0 + \Delta I \cdot \cos\left(\frac{2\pi}{N} k_0 x\right) + n(x,y) \]

Take Fourier transform...

\[ \hat{I}(k_x, k_y) = I_0 \delta(k_x, k_y) + N^2 \Delta I \cdot \left[ \delta(k_x - k_0, k_y) + \hat{n}(k_x, k_y) + \delta(k_x + k_0, k_y) \right] \]

How would an **ideal observer** decide which of the two images has the "signal" (of some **unknown frequency** \( k_0 \))?
Example: ideal observer

\[
\text{if } \frac{\max_{k > 0} |\hat{I}_1(k)|}{\text{mean}_{k > 0} |\hat{I}_1(k)|} > \frac{\max_{k > 0} |\hat{I}_2(k)|}{\text{mean}_{k > 0} |\hat{I}_2(k)|} \text{ then return "I1"
else return "I2"}
\]
I_0  =  100,  k_0 = 6   (These don't matter for ideal observer,  why not ?)

standard deviation of noise is 3,   N = 512 (These matter.   Why ?)
Recall image motion

true velocity

normal velocity (perceived)
Recall lecture 11: motion constraint equation

\[ 0 = \frac{\partial f}{\partial x} v_x + \frac{\partial f}{\partial y} v_y + \frac{\partial f}{\partial t} \]
What if there is noise?

\[ O = \frac{\partial f}{\partial x} v_x + \frac{\partial f}{\partial y} v_y + \frac{\partial f}{\partial t} \]

add noise here
add noise

unique solution

NOT unique solution
Example task:

adjust an arrow to indicate the perceived direction of motion
Interesting case:

Intersection of constraints solution is upwards (and to the right), even though the normal velocities are both downward (and to the right).
When signal to noise ratio is low (low contrast lines, or large noise), the perceived direction of motion is downward to the right.
Psychophysics 2: Noise

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- surface slant

Thursday, Oct. 29, 2015
Example: surface orientation from "texture"
Surface orientation can be estimated using these "cues":

- size gradient
- density gradient
- foreshortening of texture elements (aspect ratio)

For regular texture such as on the previous slide, these estimates are quite accurate.

What about for more natural *random* textures?
Q: How do we perceive orientation?
A: No foreshortening, no size and density gradient.
Perceived orientation is given by foreshortening and (to a lesser extent) size gradient.

Focus and density may provide info too.
Foreshortening and size provide less information when the shapes of the texture elements is random.
Which cues are used to estimate surface orientation here?
Using artificial random textures such as below, one can investigate formally the cues that are used to perceive surface orientation.. namely size, density, foreshortening.
Example task

Given two images (reference and test) of a textured surface, decide if the test has greater or lesser slant than the reference.

The threshold \( \Delta \theta \) is called the "just noticiable difference" (JND).
Many studies have compared the strengths of size ("perspective"), density, and shape ("compression") cues. In each of the above 8 examples, each cue is either present or not.
In the last two decades, many studies have used probability models. By changing the variability (noise) in each cue, one can affect the reliability of the cue. One can also compare human performance to that of an ideal observer.

Let's look at this idea for perception of surface orientation (slant) from texture.
Size of surface texture elements

See Fig 7 of http://www.cvs.rochester.edu/knill_lab/papers/21_texture_ideal.pdf
Density of surface texture elements

regular  jittered
Shape and orientation of surface texture elements

noise

uniform non-uniform

uniform non-uniform
Example: when all three cues are present, $\Delta \theta$ threshold is larger (performance is worse) when $\theta_{\text{ref}}$ is small i.e. when surface has small slant.
The same is true for ideal observers.

Note: humans perform worse than ideal.
Terminology: "slant" $\theta$ (usually $\sigma$) versus "tilt" $\tau$
Oral Presentations Papers ....

CUE COMBINATIONS AND BAYESIAN METHODS

- "The generic viewpoint assumption in a framework for visual perception" Freeman WT. Nature (1994) (PDF)
- "Cardinal rules: Visual orientation perception reflects knowledge of environmental statistics." A R Girshick, M S Land (PDF)
- "Motion direction, speed and orientation in binocular matching" R. van Ee and B. L. Anderson, Nature (2001)
- "Do humans optimally integrate stereo and texture information for judgments of surface slant?", DC Knill and J Saur (PDF)
- "Slant from texture and disparity cues: optimal cue combination", Hillis J.M., Watt S.J., Landy M.S. & Banks M. S. J.
- "Bayesian modeling of cue interaction: bistability in stereoscopic slant perception" R van Ee, WJ Adams, P Mamass (PDF)
- "Vergence and accommodation conflicts hinder visual performance and cause visual fatigue", DM. Hoffman, AR. G
Course Title: *Image Processing and Computational Photography*

Course Number: ECSE 683

Term Offered: Winter 2016

Credit Weight: 4 credits

Prerequisites: An undergraduate course in Signals and Systems

Course Instructor: Professor James Clark

Topics to be covered in the course

1. Photometry and radiometry, plenoptic function and lightfields
2. Multi-dimensional Fourier transforms
3. Multi-dimensional signal sampling theory
4. Image formation and 2D camera technologies
5. Stereo and panoramic cameras
6. Lightfield cameras
7. Image blur and coded aperture cameras
8. High Dynamic Range techniques
9. Image quantization and coding
10. Image enhancement
    a. Image deblurring and super-resolution
    b. Sensor noise models and image denoising
11. Image manipulation, rectification and reconstruction (warping, morphing, inpainting, matting, compositing)
12. Image mosaicking - building spatiotemporal and 3D panoramas