WEEK 5: BRIGHTNESS* PERCEPTION

1) Brightness assimilation
2) Grossberg and Todorović (T) implementation of BCS/FCS
3) G & T simulations
4) Integration models (e.g. Retinex)
5) Challenges to brightness models

INTERLUDE: DEFINITION OF ASSIMILATION
Consider bars of three luminances on a background of a fourth (intermediate) luminance.

Brightness assimilation: Brightness of medium luminance ("gray") bars varies in the same direction as the brightness of the nearby bars; they become more similar ("assimilate") to the perceived color of their neighbors than would be the case if presented alone. Effect is opposite in direction to that of brightness contrast.

Is this effect just “blurring” of high-spatial frequency regions?

BRIGHTNESS: To contrast or to assimilate; that is the question!

MORE ASSIMILATION

Once again, we encounter a word whose usage among researchers is inconsistent.

Assimilation is often used purely descriptively to refer to any color perception effect -- including achromatic color (lightness) or brightness -- in which a perceived color (A) is "more similar" to some nearby color (B) than would be expected if the part of the stimulus corresponding to (A) occurred alone.

Others use the word assimilation to refer only to instances where the “more similar” color effect can be arguably traced to “mixing” of signals by early receptive fields, because the stimulus parts (A) and (B) are too close together -- often they are adjacent -- to be fully resolved.
WHETHER ‘TIS NOBLER . . .
What determines whether the brightness of a visual entity (e.g., line, disk, blob, whatever) will contrast with the brightness of surrounding entities or assimilate toward their brightness?*

The following claims have been advanced, at some point, by some people, about assimilation. NOTE: They may be incorrect!

Claim 1: Perceptual objects contrast with other objects; parts of an object or objects in a group assimilate to each other.

Claim 2: Contrast occurs between a “figure” and its “ground;” assimilation occurs among objects within a background.

Claim 3: Contrast occurs within attended parts of a scene; unattended parts of a scene assimilate to each other.

* Memo to Piers: This will remain a “thermos” question until an adequate theory of brightness is formulated.

FOOD FOR THOUGHT
How does the visual system treat a simple “bull’s eye” display?

from Gilchrist 1994

Note: Most simple models (e.g., shunting network, Cornsweet-style filtering theories, even G & T, 1988) implicitly treat a bull’s eye as depicted on the left, while the visual system chooses the interpretation on the right.

Bottom line: There may be no escaping the issues of figure/ground and depth, even for the simplest “2-D” displays.

ALTERNATIVES TO RETINEX
The intuitions of Land’s (1977) Retinex theory -- specifically, those concerning edges and relatively homogeneous regions -- could be developed in several ways.

Consider:

Diffusive filling-in as a mechanism for an isomorphistic account of brightness phenomena.

Recall from Lecture 1:
Filling-in is a “fix” for “featural noise suppression” (!) so we do not experience a world of colored edges.

Issues: inherent “seriality?” one-shot alternative? Fischl/Schwartz

Role of complementary representations -- boundaries and (color/brightness) features
Note: The questions of whether we really need filling-in, of whether filling-in is performed by a diffusion-like process, of how to computationally speed up the computation of a diffusion-like process, and what are the “real” biological time delays involved in any “filling-in” process have received a great deal of attention in the published literature in recent years.

The CN530 syllabus contains a great number of pointers to more comprehensive and more recent treatments of these and related questions than we will be able to examine in depth in the course. If you decide to pursue these questions, please make use of these pointers.

Next, consider **BCS/FCS interaction:**

Many aspects of BCS will be put off until the next weeks. For now:
- What are BCS signals “for”?
- How does the “branching” from MP and “rejoining” work?

**ICONOGRAPHY 101**

Recall the diagram on this panel and try to locate its themes in the following diagram (next panel):

**Hint:** Not all of the themes are in the next panel!

**Boundaries:** Completion
- oriented
- inward
- insensitive to direction-of-contrast

**Surfaces:** Filling-in
- unoriented
- outward
- sensitive to direction-of-contrast

**NO CHEATING!**

**G & T (1988) macrocircuit:**
A few points about G & T, 88:

Q. It is neither the first nor the “latest and greatest” instantiation of a “filling-in” model. Why then study it?

A. As a model it has a good “granularity” for exploring the transition from the highly abstract treatment of Grossberg’s shunting networks (circa 70s and early 80s) to the more detailed local circuit models of today. That is, it’s degree of complexity as a model is much higher without being “out of reach” for a first-semester course. Similarly, degree of fidelity to underlying physiology is also much greater (than that of the stand-alone shunting network) without being so detailed that you’d need to spend half a year researching the latest physiology data just to understand it.

Also, as research articles go, it is relatively tutorial in its exposition.

All this said, G & T, 88 is not the best we can do for modeling lightness and brightness. Paths to further exploration are contained in the syllabus, in next week’s lecture, and are also available via further discussion.

**LEVEL 1**

Let \( I_{ij} \in \{1,2,...,9\} \) (input quantized to nine levels) For image: To filter with “Gaussian”:

\[
\begin{array}{cccccccc}
1 & 1 & 1 &  \\
1 & 4 & 1 &  \\
1 & 1 & 1 &  \\
\end{array}
\]

“extend” the outermost pixel values.

(This is not the only way to handle image boundary artifacts.)
LEVEL 2

Build DOG kernels for distance-dependent shunting network with:

\[ C_{pqij} = C \exp \{- \alpha^2 \log 2 [(p - i)^2 + (q - j)^2]\} \]  \hspace{1cm} (A4)

\[ E_{pqij} = E \exp \{- \beta^2 \log 2 [(p - i)^2 + (q - j)^2]\} \]  \hspace{1cm} (A5)

**Q:** Why the “log 2”? Note: “log 2” stands for a CONSTANT -- the log of 2; you are not meant to take the log of what’s in the square brackets [ ].

**SUPPRESSION OR SURPRISE?**

Shape of weighted gaussians used in 1-D simulations:

Do these parameters support "featural noise suppression"? How can you tell? Why did G & T use these parameters?

ON AGAIN, OFF AGAIN

**G & T** define ON and OFF cells by:

\[ \bar{C}_{pqij} = E_{pqij} \]  \hspace{1cm} (A8)

\[ \bar{E}_{pqij} = C_{pqij} \]  \hspace{1cm} (A9)

**Q1:** How biologically accurate is this?

**Q2:** What happens to OFF-cell output in simulations?

LEVEL 3

“Simple scheme” for oriented detectors

A “self-similar” (sic) basis for simple cells. Cf. Watson & Ahumada (1989) and others.

NOTE: This scheme is also a DOG, but from shifted gaussians a.k.a. “DOOG” -- difference of offset gaussians
MODEL SIMPLE CELLS

\[ F_{pqij}^{(k)} = G_{pqij} - H_{pqij}^{(k)} \quad (A13) \]

G is at the center; H gets displaced, relative to orientation, k.

\[ G_{pqij} = \exp\left\{-\gamma^2 \left[ (p - i)^2 + (q - j)^2 \right] \right\} \quad (A14) \]

Compare \( \gamma \) to \( \alpha, \beta \) of Level 2 gaussians . . .

For G & T’s purposes, BCS structural scale << FCS (Level 2) structural scale.

LEVELS 4 AND 5

Level 4: Complex cells -- via simple *rectification*

\[ Z_{ijk} = Y_{ijk} + Y_{ij[(k+K)/2]} \quad (A19) \]

Note that subscript of second Y should indicate “mod K.”

Level 5: Sum boundary signals *across* orientations at each position.

Q: Does this step require a separate “neural” layer?

BOUNDARY-GATED DIFFUSION

\[ \frac{d}{dt} S_{ij} = -MS_{ij} + \sum_{p.q \in N_{ij}} \left[ S_{pq} - S_{ij} \right] P_{pqij} + X_{ij} \quad (A22) \]

\[ P_{pqij} = \frac{\delta}{1 + \varepsilon (Z_{pq} + Z_{ij})} \quad (A23) \]

Locate: (1) “source,” (2) “sink,” (3) variable “diffusion coefficient,” (4) “density gradient” (conductance)

BCS/FCS DIFFUSION

“Just average between boundaries.” -- NOT!!!

This system is *nonconservative*. (To be discussed further.)

Aside: A closed form solution for the equilibrium of the G & T diffusion exists; it involves inversion of a large banded matrix.

QUESTION 1: What's a “syncytium”?
QUESTION 2 (Schwartz): Is diffusion plausible? timescale?

Cf: “anisotropic diffusion;” “geometry-driven diffusion,” “conductance-based diffusion” (Malik and Perona, 1987, . . . )
SIMPLE EXAMPLE

Functional scales:
BCS peaks are spatially narrower than FCS peaks (and troughs).

NOTE: This is a contingent statement about G & T simulations, NOT a deep truth about BCS/FCS (despite “Retinex” motivation!)

BRIGHTNESS CONSTANCY

G & T, Fig 10a

G & T, Fig 10b: Note “ratio-sensitive” (!) edges in FCS for “discounting the illuminant.”

Compare this simulation of brightness constancy to the UMAP non-distance-dependent network argument!

“WATCH WHAT WE DO, NOT WHAT WE SAY”

A “single scale” simulation in G & T (1988) contains three important scales of interaction. (Cf. Orwell: “War is peace.”)

BCS: (smallest) responds with fine localization to input discontinuities; ignores homogeneous regions and shallow gradients.

FCS, Level 2: For these simulations, responds somewhat similarly to BCS (aside from orientation and rectification!), but with significantly wider spatial kernels. Responds to somewhat lower “spatial frequencies”; is more likely to exhibit interactions (e.g. peak shift, smoothing) in the presence of two nearby discontinuities.

BCS/FCS interaction by diffusion, Level 6: Largest scale, at least potentially. More importantly, functional scale of diffusion is almost arbitrary, depending on layout over the entire scene of discontinuities registered by BCS and FCS.

Recall: Structural scale of diffusion equation is given by nearest neighbor interactions!

Bottom line: The power of the procedure comes from the flexibility afforded by the “chameleon-like” functional scale of the context-sensitive BCS/FCS interaction.

Urgent Memo

Lightness and brightness are both aspects of achromatic appearance.
We’ve got:
(1) dim to bright, vs. dark to light
(2) perceived illumination vs. perceived pigmentation.

BUT: consider that not all parts of all achromatic scenes can be equally well described as having brightness or lightness!

Heinemann: A decrement on a background of higher luminance has no “brightness.” Brightness is an attribute of light sources or shiny objects or of things that reflect so much light compared to their backgrounds that they might as well be light sources (moon; Gelb effect.)

So, some parts of some scene have no “brightness.”

Nor is lightness universal: Consider the appearance of tinted liquids. (transparent or “film” color modes; cf. Katz).

Lightness is an attribute of those regions in a scene that give the appearance of being parts of opaque surfaces.

What about “laboratory” displays?
THE PLAN

Recall re: G & T simulations:

**relative structural scales** (space constants of gaussians) in BCS vs. FCS

**variable functional scale** of FCS diffusion -- i.e.,
"Go until you are blocked."

**nonconservative** form of diffusion equation: results in *dynamic balance* of lightness-coding activity replenished from sources (bottom up signals from model retina/LGN) and draining from sinks (individual cell’s decay rate) as gated by boundaries.

Consider also:

BCS signals are analog-valued, therefore *blockage of diffusion may be partial.*

What about time? Is diffusion “plausible”? Does perceptual “filling-in” take a measurable amount of time to occur? If so, how long does it take to occur, and over what distances?

See papers by Paradiso and Nakayama and Davey et al. in your syllabus for a start on this topic.

NOTE: In this week’s notes, many figures from *G & T, 1988* are reproduced. The reproduction quality in these notes is at times poor, but the figure number is always legible, so you can refer to cleaner figures in your copy of the article.

BRIGHTNESS CONSTANCY AND RATIOS

Note: functional scales -- BCS peaks are spatially *narrower* than FCS peaks (and troughs).

Note: only ON cells are used for FCS in *G & T* simulations.

Note: ratio-sensitive contours (in FCS!) for *discounting the illuminant.*

Q: Where are these “contours in" the diagram?

Compare this simulation of brightness constancy to the UMAP non-distance-dependent network situation.

As noted last week, having BCS peaks be narrower than FCS peaks and troughs is a contingent statement about the present *G & T* simulations, NOT a deep truth about BCS/FCS.

 Stranger than fiction: What would it mean for “edges” (BCS boundary signals) to be as wide as “regions” (FCS feature signals)? Think: geometry, units, ...

The phrase “boundary web” was coined with such a situation in mind. You’ll encounter that phrase again later.
BRIGHTNESS CONTRAST

Small targets: different output from same (local) input

Fig 10

Large targets: different output at A' and B' from same FCS SIGNAL at A and B
(rationalized by diffusion mechanism; cf. Cornsweet account of COCE: how would he handle small vs. large?)

COCE SIMULATION

Note critical role of outer step discontinuities in generating barriers to filling-in.

A real step discontinuity: Compare these two simulations with Cornsweet's account of why COCE looks like a step.

Fig 14

CONTRAST AND SHALLOW GRADIENTS

What are the (presumed!) respective physical reflectances of the two patches?

What are their Grossbergian reflectances . . . with respect to global frame of reference? . . . with respect to local frame of reference?

Amount of contrast is coded by “ratio-sensitive” peaks and troughs in FCS.

JUST HOW RATIO-SENSITIVE IS IT?

Q: Did you think to generate a plot like this for Simulation Assignment 1?

Make sure that you really understand this plot!
SIMULTANEOUS ASSIMILATION AND CONTRAST (?)

Shapley and Reid (1986) describe a “mixture” of assimilation and contrast effects:

Note the pattern of FCS signals when two step discontinuities fall within a single DOG structural scale!

ICONOGRAPHY 101

G & T use a symbol SIZE code, rather than a luminance code, for brightness simulations.

(Neural modeling research is often limited by a researcher’s inability to “see” what a model is doing!)

Figs 3, 4, 5

CONTRAST POLARITY, ORIENTATION, & PREPROCESSING

Fig 6: Do the patterns in (a) and (f) make sense to you?
**CLOSURE AND FILLING-IN**

Note the crucial role of **closed compartments**, including parts made from step boundaries, as well as cusp boundaries, in this configuration of COCE.

**Fig. 18**

**UNBOUNDED DIFFUSION**

No outer boundaries => no COCE.

Compare with your own percept: the cusp looks like . . . a cusp!

**Fig. 19**

Demonstrates the inadequacy of claiming that a *thresholded gradient operator* (or, equivalently, *attenuation of low spatial frequencies*) is the only important part of COCE explanation.

**LITTLE LINE -- BIG EFFECT**

**TO ERR IS HUMAN**

G & T simulation agrees with percept of Shapley (1986). [square outlines added here] Old Retinex fails ... by providing a *more veridical* output than humans do.

**Fig 24**
HOW LOCAL IS "LOCAL"?

G & T equations produce a higher output for upper square [outlines added here] even with an "illumination gradient."

Such a “quasi-local” gain control has some advantages over global normalization.

Fig. 25

INTEGRATION THEORIES

Arend and Goldstein (1987) agree with Land and with T (1987) and G & T (1988) on the need for (mechanistic) recovery of lightness (!) in suppressed regions (i.e. far from edges.)

But, they...argue for “global” integration (as opposed to “local” filling-in.)

Recall: the local diffusion process of G & T can span large regions.

INTEGRATION: ALTERNATIVE TO FILLING-IN

From A & G:
“Figure 2. Sketch of low-frequency attenuation argument. Attenuation alone predicts similar appearance, but the wrong appearance. Adding an integration stage produces the observed appearance.”

Note: luminance sawtooths act much like luminance cusps.

Compare to T's (1987) argument about explanatory adequacy of Cornsweet-style explanation of COCE.

* spatial integration vs. “filling-in”
RETINEX AND OTHER INTEGRATION MODELS

A & G summarize the “1-D” computational theory of classic integration-models (e.g., Retinex) as shown...

To compute:
a quasi-line integral
(“quasi” because of threshold)

Problem: Value of integral is generally path-dependent due to threshold.

Retinex solution:
use average integral over many paths.

DIV, GRAD, CURL, AND ALL THAT

Q: Is this your idea of a page from a psychology journal?

A & G propose that a better formulation of integration theories is to find a scalar field whose (thresholded) derivative is the observed (thresholded) derivative of the image.

Now the “problem” is more severe!
Thresholded derivative is not necessarily a gradient of anything, so...

Integral may not exist.

WHEN NOT TO INTEGRATE

Example of dependence of integral values on path

Fig 6 of A & G

Proposed solution: Calculate local estimate of image intensity’s curl to see if you should even try to integrate across a particular boundary.

APPROXIMATION OF CURL

\[ |\text{curl } F| = \lim_{A \to 0} \left( \frac{1}{A} \right) \oint F \cdot \mathbf{t} \, ds \]

Curl calculations is (just) a diagnostic for “field segmentation,” to tag boundaries over which you cannot integrate.

Numerical approximation:
First, “hexagonal sampling”

\[ C = \sum_{n=2}^{6} w_n (L_n - L_{n-1}) + w_1 (L_1 - L_6) \]

Set threshold for w’s so that difference of 1 is treated as 0.
**EDGES THAT ARE NOT TO BE INTEGRATED OVER**

Natural origins of nonzero curl condition

Occluding object:

3-D Corner:

Edges of Mondrian within a flat plane are (probably) okay to analyse.

From here to here integration is not advisable.

**Bad edges**

Circularity: Does “discounting the illuminant” require solving the entire 3-D layout problem? How could you do the latter without being able to tell an illumination edge (e.g. shadow) from an object's occluding edge?

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**ALAN GILCHRIST**

Alan Gilchrist (1979, *Sci Am* 240, 112-124) is a pioneer of the study of the effects of perceived 3-D layout on **lightness** judgments.

See next panel for explanation of this display.

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**TED ADELSON**

Ted Adelson has contributed a number of striking demos on lightness, brightness and transparency; his papers are available for download at 
http://www-bcs.mit.edu/people/adelson/papers.html

papers of particular interest include:

- Perceptual Organization and the Judgment of Brightness
- The Perception of Shading and Reflectance (with Pentland)

[This is one of the most accessible expositions available anywhere on “cost functional” models in vision.]

LAYERS AND LIGHTNESS

The luminances of the two correspondingly labeled regions in each panel (e.g. a₁ and a₂) are the same.

EVER POPULAR JUNCTION TYPES

Cf. Logvinenko demo, Week 5, panel 10 & Waltz effect, Week 1, panels 62-64.

ALL OR NOTHING?

One more time:

A number of demos suggest that it may be necessary to model the entire machinery for perception of 3-D surface layout at the same time -- note that I did not say “before” -- as modeling brightness and lightness perception in order to truly succeed at modeling any of those phenomena.

IMPOSSIBLE STAIRCASE

Returning for a moment to “2-D” (or “quasi-2D” !) displays:

A & G’s curl diagnostic says:
“Don’t try to integrate across this pattern.”
IMPOSSIBLE STAIRCASE

G & T simulate the percept of the “impossible staircase,” without the benefit of a curl computation.

Why does this simulation produce the correct output?

TRANSITIVE EFFECTS ACROSS EDGES?

Integration theories have a prima facie advantage over boundary-gated filling-in theories . . .

whenever a percept depends on transitive relations among luminances across two edges.

Grossberg, 1983 discusses the Arend et al. 1971 effect:

stimulus

percept

Q: Why don’t G & T, 1988 show a simulation of this percept?

Recall: simulation of the Shapley & Reid experiment -- panel 10 of these notes -- DID handle a seemingly related display.

STAIRWAY TO MODELING HEAVEN

Coren’s commentary on Grossberg, 1983 criticizes filling-in by pointing out a situation in which he claims it fails.

Coren (incorrectly!) assumes that Grossberg’s 1983 concept of filling-in will incorrectly predict a perceived staircase for stimulus c, by repeated application of whatever it did to correctly predict appearance b from stimulus a.
Cohen & Grossberg’s, 1984 simulations handle Coren’s objections effortlessly.

These simulations were performed within the “filling-in resonant exchange” (FIRE) formalism, rather than BCS/FCS, but the key boundary-gated diffusion properties are already in the FIRE theory.

Only the first and last cusps are “perceived” as steps by the model; interior regions look alike, with same mean brightness, in accordance with human percept*.

WHY?

*More psychophysics needs to be done!

G & T’s simulation of a related pattern “works” for similar reasons.

Question 1: What output would G & T 1988 produce for a stimulus containing a series of luminance STEPS?

Question 2: How does YOUR visual system perceive a series of luminance steps?

Now what?
The same properties that “save” filling-in from Coren’s criticism about a series of COCE edges will guarantee a wrong result for a luminance staircase.

One proposed solution is to do filling-in at multiple spatial scales.

**ALTERNATIVE: DIRECTIONAL FILLING-IN**

Note: in DFI, boundaries are permeable to flow only from regions of low potential to regions of high potential. (!)

**Excerpts from Arrington, 1996, Figure 5:**

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FILLING-IN THEORIES NOT CREATED EQUAL

While (basic) filling-in theories have difficulties with *transitivity*, classical (global) integration theories have no intrinsic measure for when to attenuate propagation effects over “legal” edges.

Their scales of interaction are either purely *local* (thresholded derivative step) or *global* (integration step), but not *intermediate*.

Integration theories therefore incorrectly predict a perceived staircase for Coren’s stimulus, (as Coren *assumes* of filling-in, and as happens for DFI).

*But Rudd, personal communication, Jan. 2002 has other ideas re: “modified” integration theories!*

Brightness and Lightness

What’s the bottom line on theories of brightness and lightness?

Arash will explain all next week!