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Research Note — Brightness and Colour Contrast

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1. Thesis

L1 (Geometric Illusions) showed that the visual system does not measure lengths objectively. L2 shows the same for **brightness** — and provides for the first time a concrete neural mechanism. The intuitive assumption that the perceived brightness of a patch depends only on its own light is refuted threefold: **the same physical luminance is perceived systematically differently depending on context.** The mechanism is **lateral inhibition** — modellable as a difference-of-Gaussians ("Mexican hat") that produces simultaneous contrast and Mach bands from *one* principle — and **brightness constancy**, which "computes away" shadows. The visual system does not measure absolute luminance but **contrasts and ratios**. The module deepens Module 09 (colour as construction) with a real neural model and continues the perception strand.

2. Assumptions

1. The physical luminance of each pixel is exactly defined and measurable.
2. Lateral inhibition is modelled as a difference-of-Gaussians (DoG) — excitatory centre (narrow), inhibitory surround (broad); an established model of retinal ganglion cells.
3. Brightness constancy is modelled as illumination estimation — the system divides out the estimated illumination to estimate the reflectance.
4. Static, achromatic stimuli (grey values); colour contrast is mentioned analogously but not computed separately.
5. Average observer; the models are calibrated to the phenomenology, the mechanisms (DoG, constancy) are neurophysiologically motivated.

3. Mathematical model

M1 — "brightness = local luminance": Perceived brightness \(H(x) = L(x)\), the luminance at location \(x\). Context plays no role.

M2/M3 — lateral inhibition (DoG): The neural response is the convolution of luminance with a Mexican-hat kernel:

$$ R(x) = L(x) * \big[G_{\sigma_c}(x) - w\,G_{\sigma_s}(x)\big], $$

with excitatory centre G_{σ_c} (narrow), inhibitory surround G_{σ_s} (broad, $\sigma_s > \sigma_c$) and inhibition weight w. Perceived brightness is $H(x) = L(x) + k\,R(x)$. This one mechanism produces: - **Simultaneous contrast** (M2): a patch on a bright ground is inhibited → appears darker. - **Mach bands** (M3): at luminance edges, over- and undershoots arise → bright/dark bands physically absent.

M4 — brightness constancy: The system estimates the illumination $I(x)$ and the reflectance $\rho(x) = L(x)/I(x)$. Reflectance is perceived, not luminance. Two fields of equal luminance but differently estimated illumination (e.g. one in shadow) appear differently bright.

Symbol	Meaning	Unit
$L(x)$	physical luminance	—
$H(x)$	perceived brightness	—
$R(x)$	neural response (DoG)	—
σ_c, σ_s	centre/surround width	px
w	inhibition weight	—
$I(x), \rho(x)$	illumination, reflectance	—

4. Parameters

Three scenarios:

Scenario	Setup
A simultaneous contrast	grey 0.5 on ground 0.2 and 0.8; DoG $\sigma_c=2$, $\sigma_s=15$, $w=0.95$
B Mach bands	ramp 0.3→0.7; DoG response
C checker-shadow	two fields luminance 0.42; illumination 1.0 vs. 0.6

Tolerance set in advance: $\varepsilon = 5\%$ (brightness), $\varepsilon = 2\%$ (Mach-band amplitude). Rationale: smaller deviations lie at the perceptual threshold.

5. Prediction

Scenario	Expectation
A	equal luminance, perceived brighter on dark than on bright
B	smooth ramp, perceived with dark and bright band at the corners
C	equal luminance, field in shadow perceived brighter

6. Falsification criterion

M1 (“brightness = local luminance”) is refuted if two physically equal luminances are perceived differently by more than ε, or if bands physically absent appear at a smooth ramp — systematically and produced by context or lateral interaction.

7. Competing models

- **K1 — local luminance (M1):** tested baseline model.
- **K2 — lateral inhibition / DoG (M2/M3):** retinal contrast enhancement.
- **K3 — brightness constancy / anchoring (M4):** illumination estimation, reflectance perception (Gilchrist).
- **K4 — Retinex theory (Land):** the visual system computes reflectance by comparison across edges.
- **K5 — Bayesian perception:** most probable reflectance+illumination given the stimulus (most general framework).
- **K6 — opponent colours / lateral inhibition in colour space:** analogous for colour contrast (connects to L3).
- **K7 — multiscale filter models (ODOG):** oriented difference-of-Gaussians, explains more complex brightness illusions.

8. Domain of failure

- **Simplified DoG model:** a single-scale filter; real perception uses multiple scales and orientations (ODOG). Complex illusions (White illusion) need multiscale models.
- **Achromatic:** colour contrast is only mentioned, not computed — own mechanism (opponent colours, L3).
- **Calibration of the model parameters:** \(k\), \(w\), \(\sigma\) are fitted to the phenomenology; the absolute amplitudes are not derived from neurophysiology.
- **Individual/adaptive effects:** brightness adaptation over time (light-dark adaptation) is not modelled.
- **Checker-shadow illumination estimation:** the estimated illumination (0.6) is plausibly chosen, not computed from a full scene model.
- **High-level influences:** familiarity, attention and 3D interpretation additionally affect brightness; not treated here.

9. Simulation

Numerical evaluation in `kontrast_simulation.py`:

1. DoG filter (Mexican hat) as a model of lateral inhibition.
2. Scenario A: luminance profile with equal grey on two grounds; DoG response; perceived brightness of both patches.
3. Scenario B: smooth ramp; DoG response produces Mach bands; over-/undershoots measured.
4. Scenario C: two fields of equal luminance; brightness constancy model; estimated reflectances.

Results in `kontrast_results.json`. Plot as `kontrast_szenen.svg` (four subplots: simultaneous-contrast profile, Mach bands, checker-shadow schematic, Mexican-hat kernel).

10. Result

10.1 A simultaneous contrast

Quantity	Value
physical grey (both)	0.500

physical ratio	1.000
perceived on dark ground	0.530
perceived on bright ground	0.487
perceived ratio	**1.087**
Assessment M1	**refuted**

10.2 B Mach bands

Quantity	Value
Ramp	0.3 → 0.7 (linear, smooth)
bright band (overshoot)	+0.045
dark band (undershoot)	−0.015
physical	no bands
Assessment M1	**refuted**

10.3 C checker-shadow (Adelson)

Quantity	Value
luminance field A and B	0.420 (identical)
physical ratio	1.000
estimated illumination A / B	1.0 / 0.6
estimated reflectance A / B	0.42 / 0.70
perceived ratio	**1.667**
Assessment M1	**refuted**

Plot: `kontrast_szenen.svg`.

11. Assessment

M1 ("brightness = local luminance") is refuted in all three scenarios.

Scenario A (simultaneous contrast) is the basic case. A grey patch with exactly the luminance value 0.5 appears brighter (0.53) when on a dark ground and darker (0.487) when on a bright ground — perceived ratio 1.087 at physically identical grey. The mechanism is lateral inhibition: the neural cells representing the patch are inhibited by the activity of neighbouring cells. On a bright ground this inhibition is strong (much light around), the patch appears darker; on a dark ground it is weak, the patch appears brighter. This is not an error but a sensible adaptation: the visual system enhances contrasts because edges and contrasts are more informative than absolute brightness (at an edge an object ends; an absolute brightness value says little by itself).

Scenario B (Mach bands) demonstrates the same mechanism in a striking way. A physically perfectly smooth brightness ramp (linear from 0.3 to 0.7) is *not* perceived as smooth: where the ramp begins, a dark band appears (undershoot −0.015), where it transitions into the bright plateau, a bright band (overshoot +0.045). These bands — named after Ernst Mach, who described them in 1865 — do not exist physically; they are pure constructions of lateral inhibition. The decisive point, and the methodological core of the module: **simultaneous contrast and Mach bands arise from the same model**, the difference-of-Gaussians filter. One mechanism, two apparently different phenomena — the same kind of unification that appeared in mechanics (resonance/beat from one model) and audio.

Scenario C (checker-shadow) is the most famous brightness illusion, constructed by Edward Adelson in 1995. Two fields of a checkerboard have *exactly the same luminance* (0.42) — and yet appear dramatically different: one as a dark field in the light, the other as a bright field in the shadow. Here lateral inhibition does not suffice as an explanation; the mechanism is **brightness constancy**. The visual system knows (from the shadow cast by the cylinder) that a region lies in shadow, thus receives less light. It "computes away" this illumination to estimate the *material brightness* (reflectance) — because reflectance is the constant, object-related property that interests us (a sheet of paper stays white, whether in sunlight or shadow). The field in shadow must, to produce the same luminance as the illuminated one, have a higher reflectance (0.70 vs. 0.42) — so it appears brighter. The illusion is the price for a normally very useful ability: colour and brightness constancy, which lets us recognise objects under changing illumination.

The central methodological lesson: unlike L1 (where the models were purely phenomenological), L2 provides a **concrete, neurophysiologically motivated mechanism** — lateral inhibition as difference-of-Gaussians, the standard model of the receptive fields of retinal ganglion cells and simple cortical cells. That such a simple model (centre minus surround) produces two classical illusions is impressive. At the same time, scenario C shows the limit of purely local models: brightness constancy needs an estimate of scene illumination, thus a step beyond pure stimulus processing. The visual system is both — a local contrast enhancer *and* a global scene interpreter.

Connection to previous modules: - **Module 09 Colour Mixing:** there colour was the construction (tristimulus); here it is brightness, with a concrete neural mechanism. Colour contrast (opponent colours) is the direct continuation in L3. - **Module L1 Geometric Illusions:** the same basic insight (perception ≠ physical stimulus), now with mechanism instead of only phenomenology. - **Module 02 Cave Allegory:** brightness constancy is a nice example that we do not perceive the stimulus (luminance) but a reconstruction of the world (reflectance).

12. Next test

Module L3 Afterimages and Opponent Colours as the next step: opponent-colour theory (Hering), negative colour afterimages, why there is no "reddish green" — the continuation of Module 09 and lateral contrast in colour space. Or **Module L5 bistable perception**.

Possible extension Module L2 v0.2: multiscale models (ODOG) for more complex illusions (White illusion, Hermann grid); colour contrast computed; Retinex theory; the role of 3D interpretation and attention.

Appendix A — Cross-references

- Practice explanation: `PRAXIS-Helligkeitskontrast-EN.md` (follows)
- Companion paper: `BEGLEITPAPIER-Helligkeitskontrast-EN.md` (follows)
- Tool: `CONTRA.html` (follows) — *Lat. contra, against; the contrast*
- Code: `kontrast_simulation.py`
- Plot: `kontrast_szenen.svg`
- Result data: `kontrast_results.json`
- Predecessor modules: Module 09 Colour Mixing, Module L1 Geometric Illusions, Module 02 Cave Allegory
- Follow-up modules (planned): L3 Afterimages/opponent colours, L4

Motion, L5 Bistability, L6 Gestalt

Appendix B — External stocktaking

- **Mach (1865)** — description of the Mach bands.
- **Hartline (1938/1949)** — lateral inhibition in the Limulus eye (Nobel Prize 1967).
- **Kuffler (1953)** — centre-surround receptive fields of retinal ganglion cells.
- **Land (1977)** *Retinex* — reflectance computation.
- **Adelson (1995)** — checker-shadow illusion.
- **Blakeslee & McCourt (1999)** ODOG — multiscale filter model.

What the workshop note adds: three contrast phenomena in a unified falsification format; the explicit DoG model that produces simultaneous contrast and Mach bands from one mechanism; the separation of lateral inhibition (local) vs. brightness constancy (global); the bridges to modules 09, L1, 02.

Appendix C — Sources

- Mach, E. (1865). Über die Wirkung der räumlichen Vertheilung des Lichtreizes auf die Netzhaut. *Sitzungsber. Akad. Wiss. Wien* 52:303–322.
- Hartline, H. K. (1949). Inhibition of activity of visual receptors by illuminating nearby retinal areas. *Am. J. Physiol.*
- Kuffler, S. W. (1953). Discharge patterns and functional organization of mammalian retina. *J. Neurophysiol.* 16:37–68.
- Land, E. H.; McCann, J. J. (1971). Lightness and retinex theory. *J. Opt. Soc. Am.* 61:1–11.
- Adelson, E. H. (1995). Checkershadow illusion. MIT.
- Blakeslee, B.; McCourt, M. E. (1999). A multiscale spatial filtering account of the White effect. *Vision Research* 39:4361–4377.

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