Angular Embedding:
from Jarring Intensity Differences to Perceived Luminance

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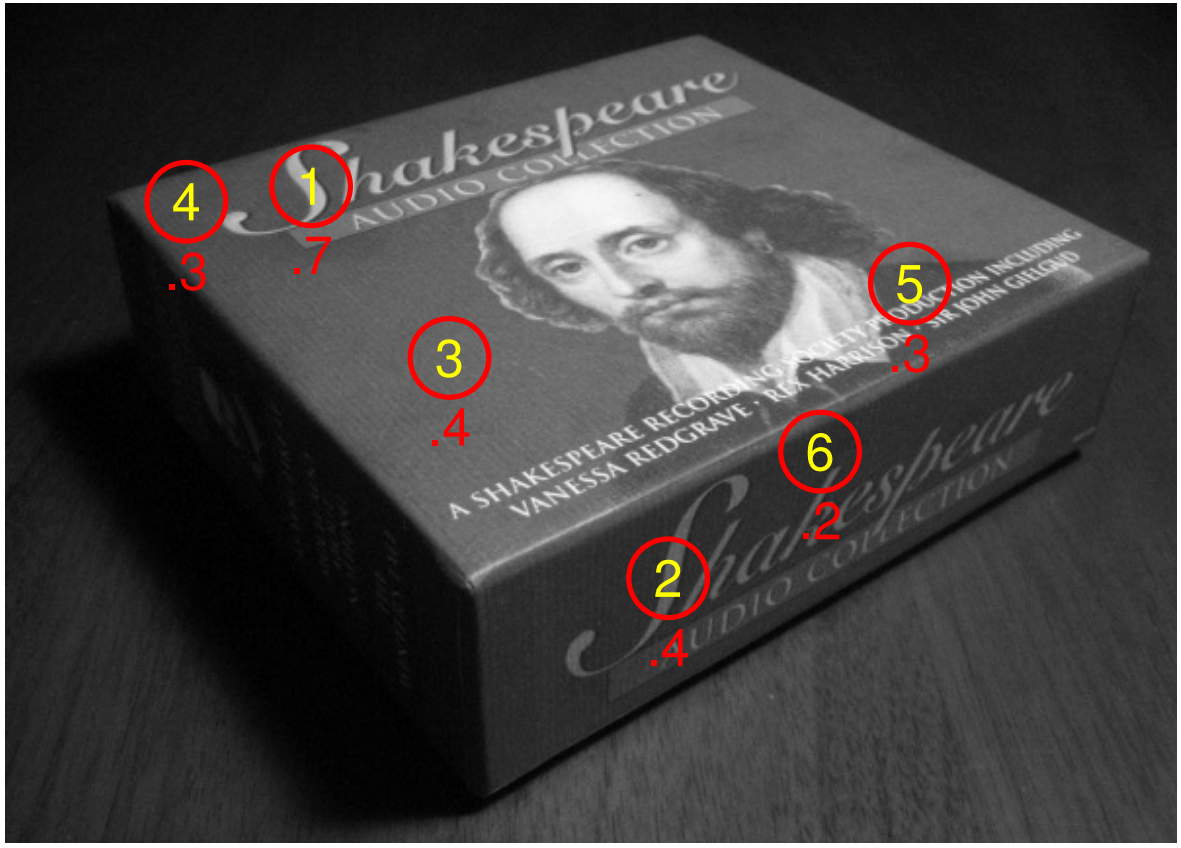
Distinction: Intensity, Brightness, and Lightness



intensity = measured luminance: $I_1 > I_2 = I_3 > I_4 = I_5 > I_6$

brightness = perceived luminance: $B_1 > B_2 > B_3 > B_4 > B_6 > B_5$

lightness = perceived reflectance: $L_1 = L_2 > L_3 = L_4 = L_6 > L_5$

Helmholtz and Hering Debate

1. Helmholtz: byproduct of high-level cognitive cause

– recover reflectance from luminance with unknown illumination
– Land & McCann, Retinex, 1971
– Barrow & Tenenbaum, intrinsic images, 1978

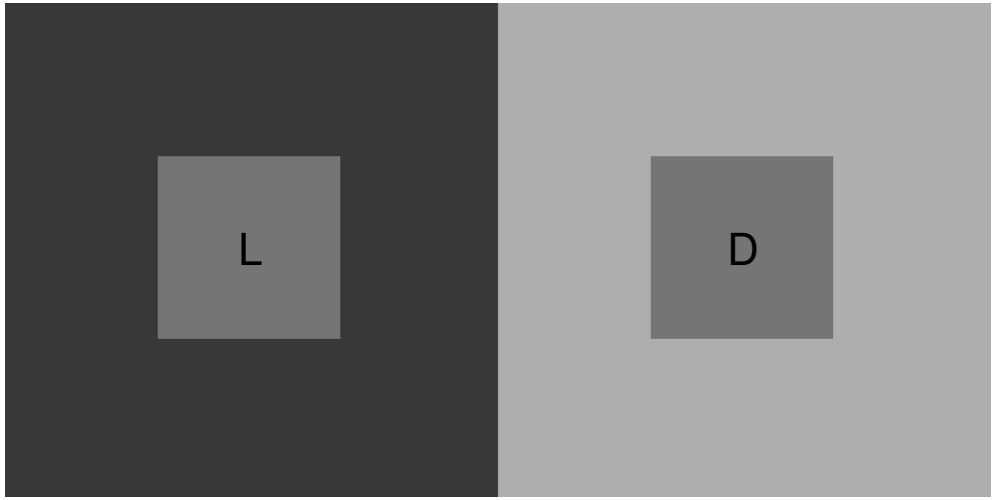
2. in-between

– Ross & Pessoa, selective integration model, 2000
– Kelly & Grossberg, Form-And-Color-And-DEpth, 2000

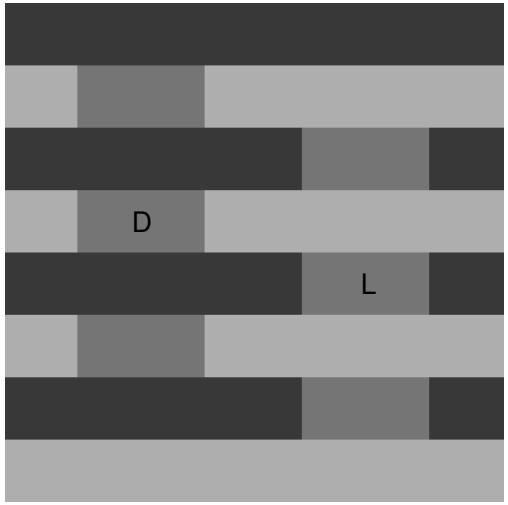
3. Hering: manifestation of low-level physiological cause

– lateral inhibition, center-surround filtering
– Blakeslee et al, multiscale filtering, 2005

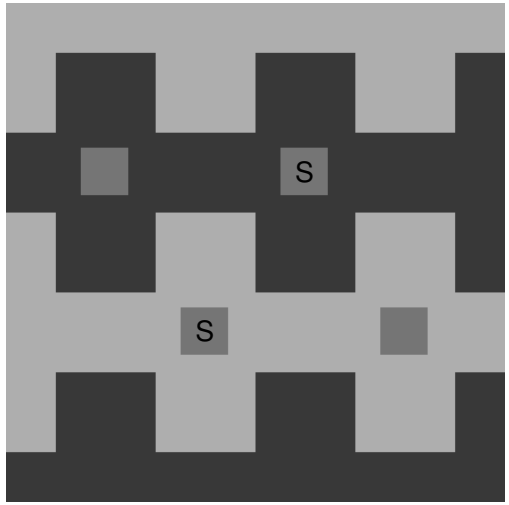
Basic Brightness Illusions



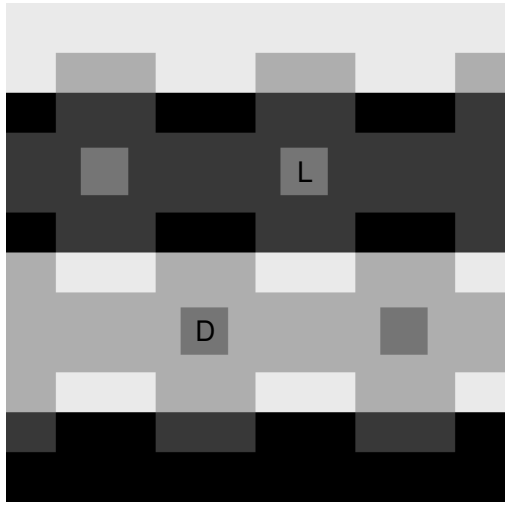
Simultaneous Contrast



White

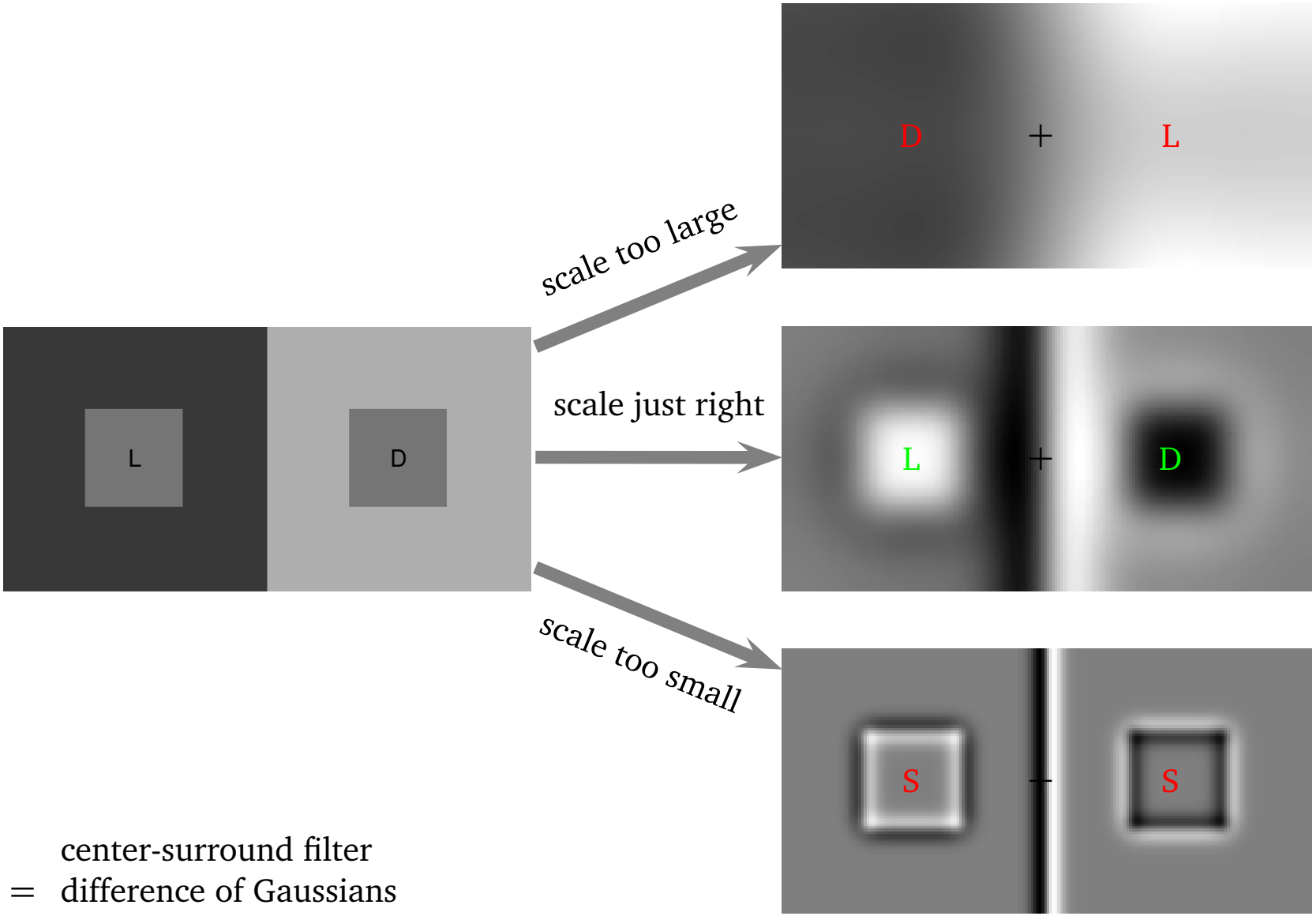


Anti-snake



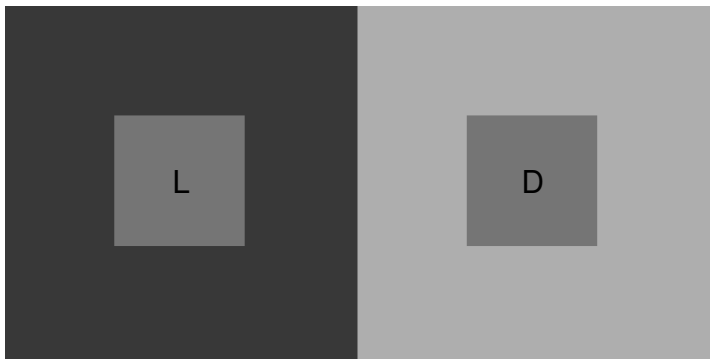
Snake

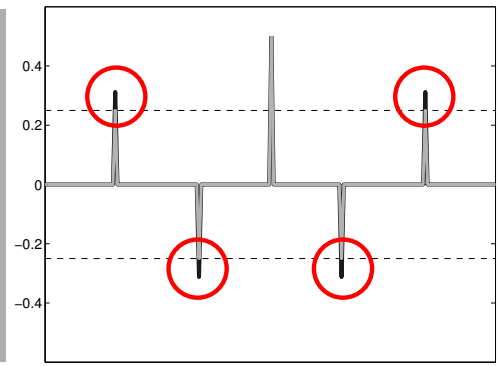
Textbook Explanation: Center-Surround Filtering

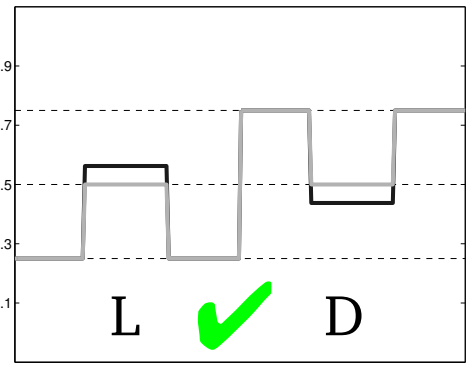


center-surround filter
= difference of Gaussians

Selective Enhancement is a Must but not by Size



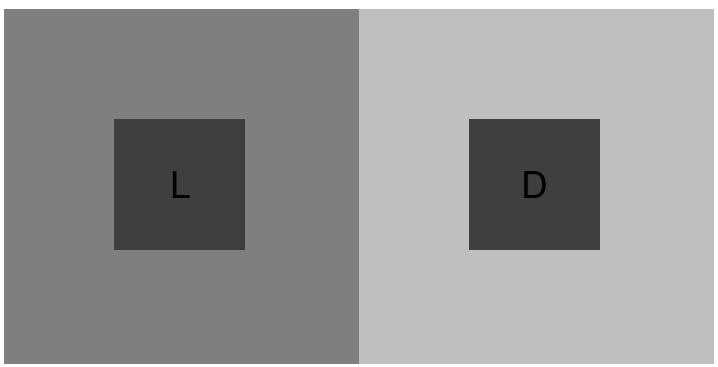


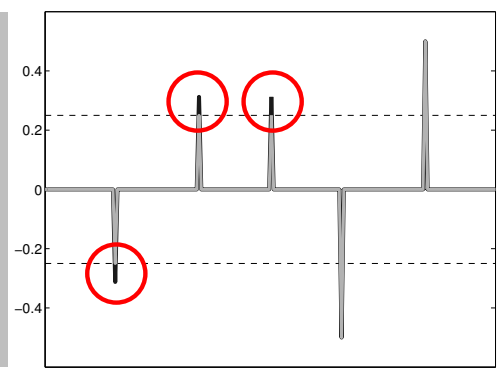


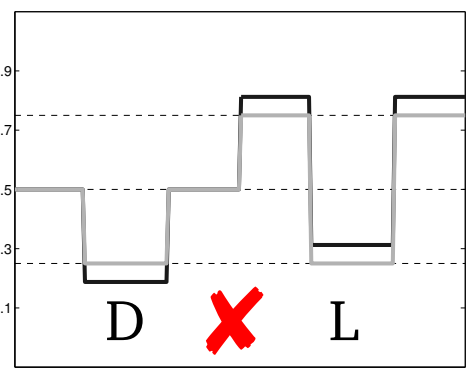
increment-decrement

derivative modified and integrated

double-decrement

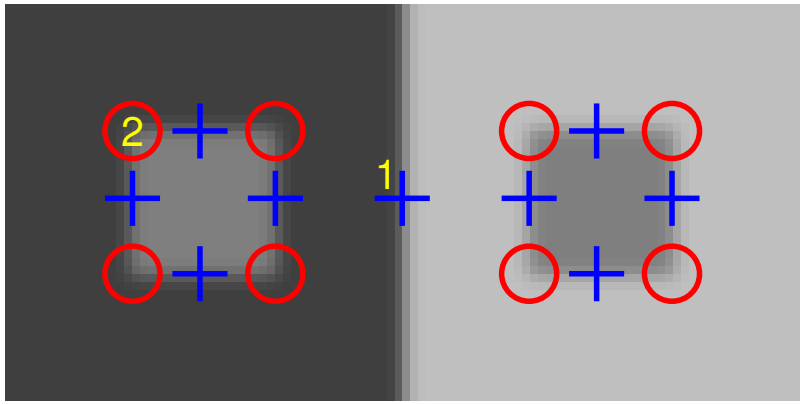




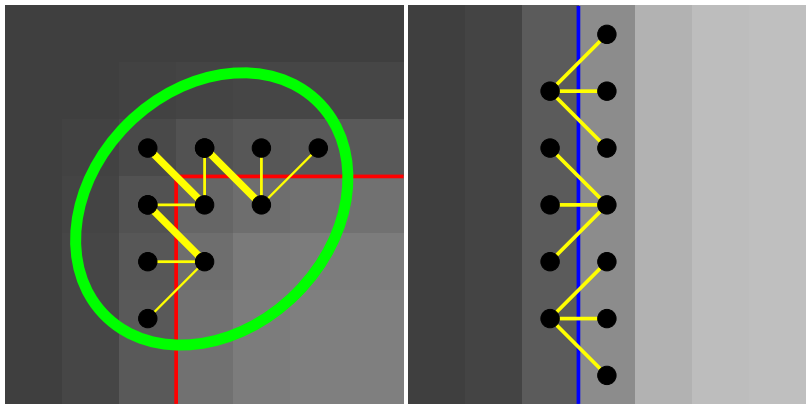


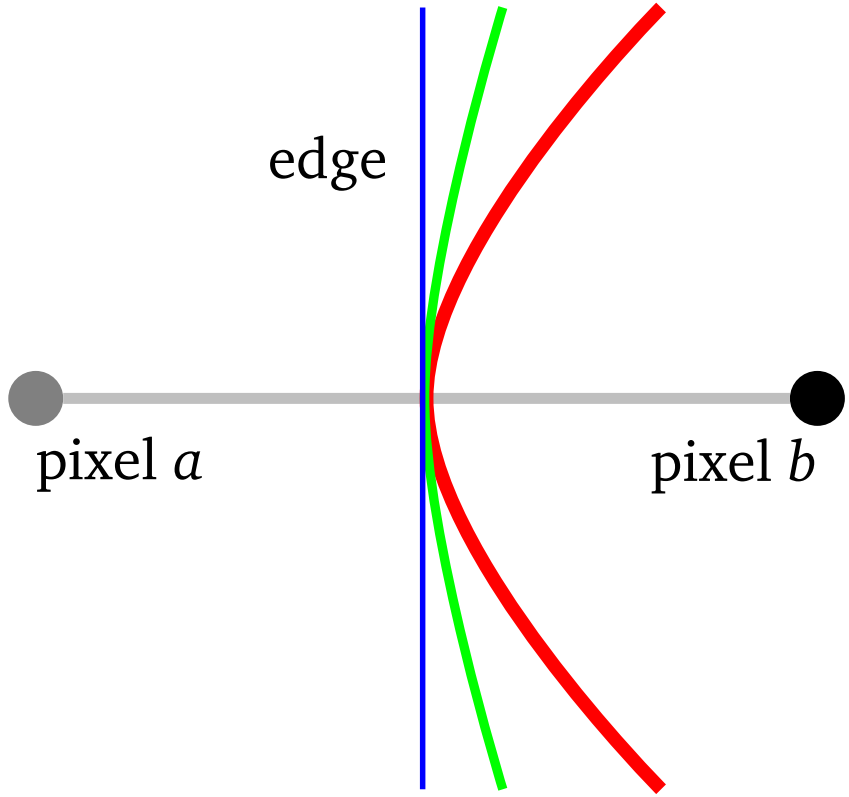
Enhancing small edges only explains one of the two illusions!

Insight: Selective Enhancement by Edge Geometry



difference intensified around a corner!

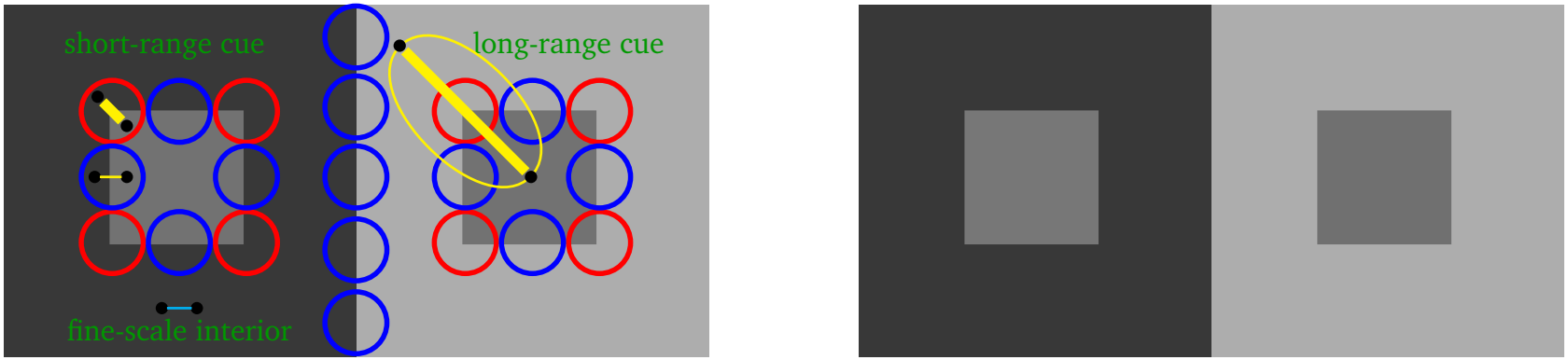




Coarse-scale differences provide the right selective enhancement.

Brightness differences across an edge increase with its curvature.

Brightness is Analogous to Motion Perception



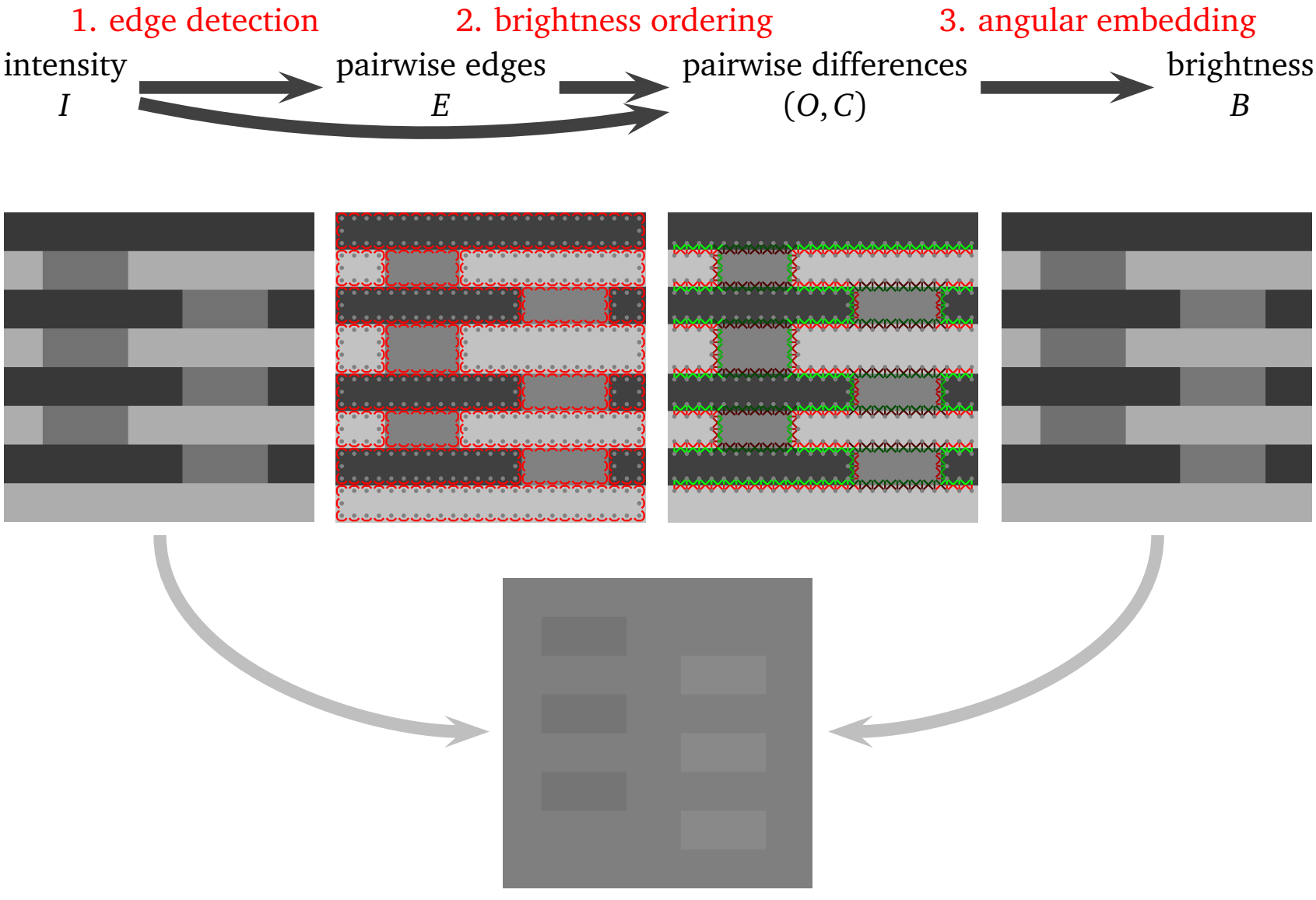
measured intensity —cue integration→ perceived brightness

1. Feature → *enable* brightness with short-range cues
   fine-scale for interiors, and coarser-scale across edges

2. Aperture → *reinforce* brightness with long-range cues
   paths of higher confidence, originating from corners, dominate

3. Integration → *realize* brightness from pairwise local cues
   maximally fulfill local orderings in accordance with confidence levels

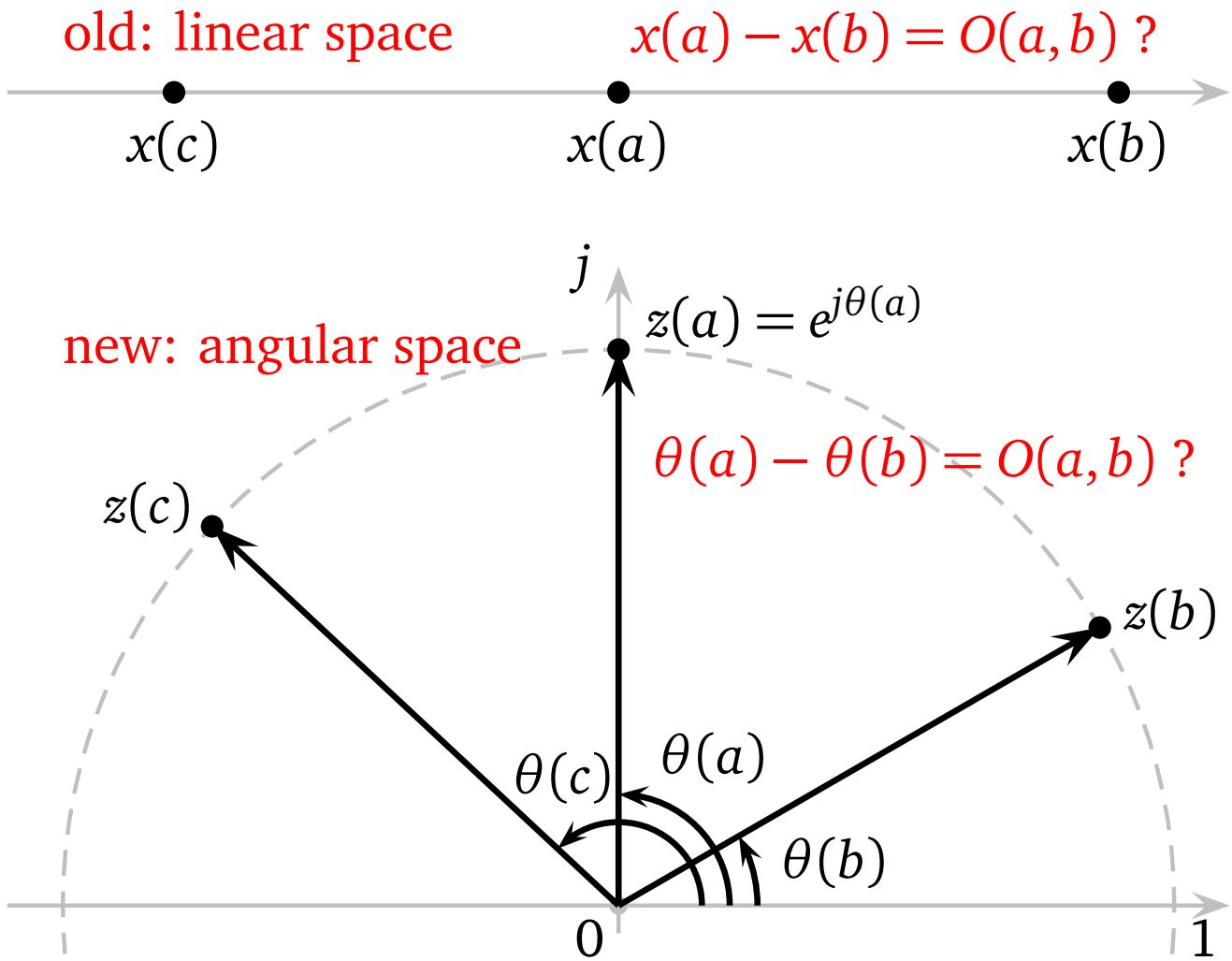
Brightness Modeling is Global Brightness Ordering



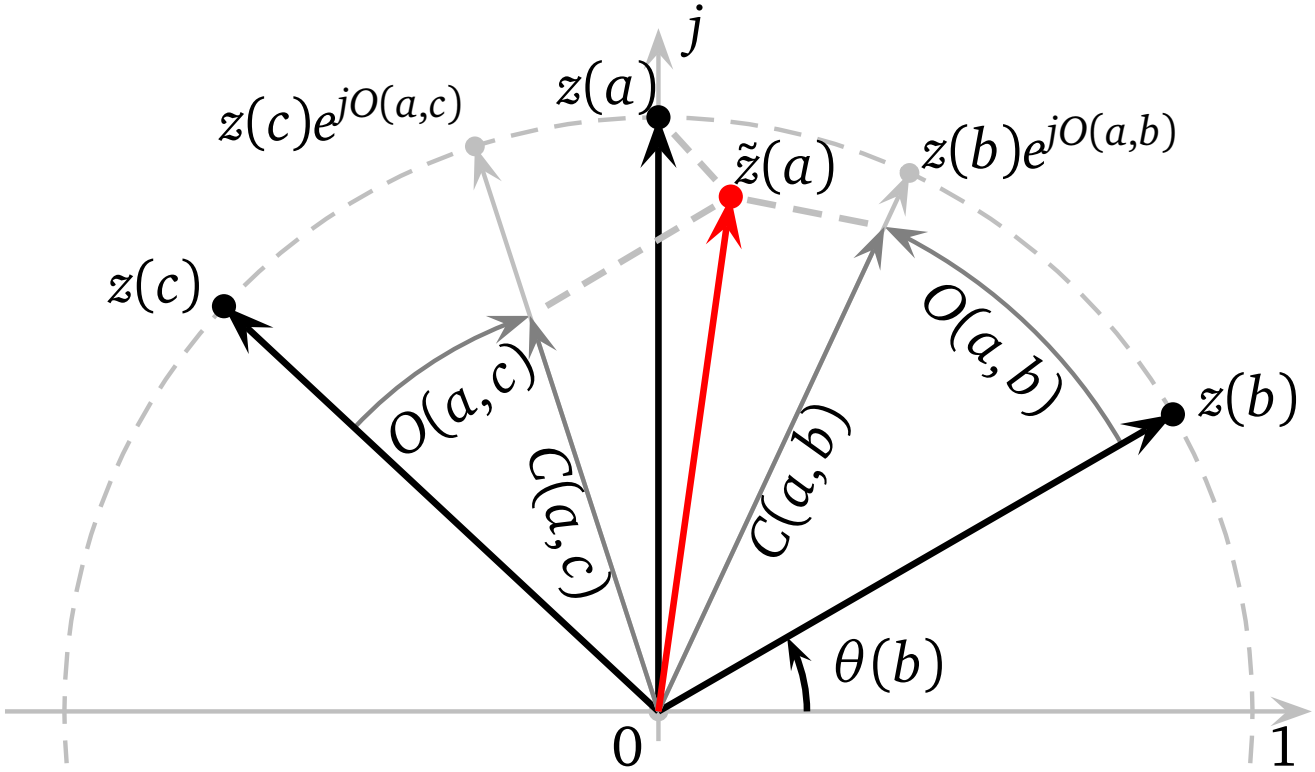
New Integration Method: Angular Embedding

input: local ordering
O = pairwise differences
C = confidence in O

output: global ordering
x = positions on a line, **or**
z = positions on the unit circle



Criterion: Minimize Distance to Local Average



minimize: $$\varepsilon(z; O, C) = \sum_a D(a,a) \cdot |z(a) - \tilde{z}(a)|^2$$

local average: $$\tilde{z}(a) = \sum_b \frac{C(a,b)}{D(a,a)} z(b)\, e^{jO(a,b)}$$

total confidence: $$D(a,a) = \sum_b C(a,b)$$

Optimum: Angles of the Smallest Eigenvector

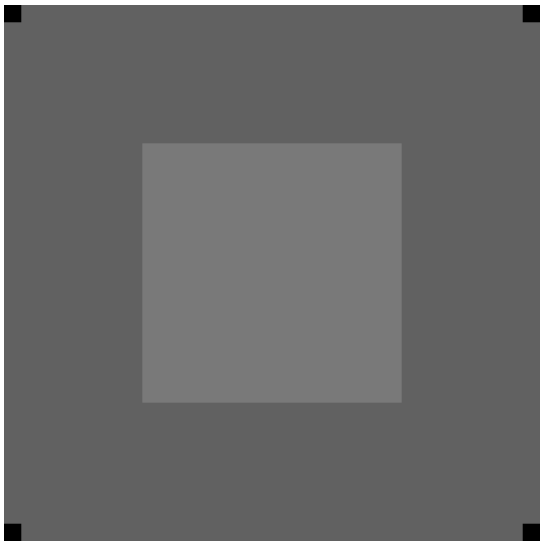
angular embedding

minimize:	$\varepsilon(z; O, C) = z' W z$
representation:	$z = e^{j\theta}$
error:	$W = (I - D^{-1}M)' D (I - D^{-1}M)$
measurement:	$M = C \bullet e^{jO}$
degree:	$D = \mathrm{Diag}(C1)$
optimum:	$\theta^* = \measuredangle z^* = \measuredangle$ smallest-eigenvector-of (W, D)

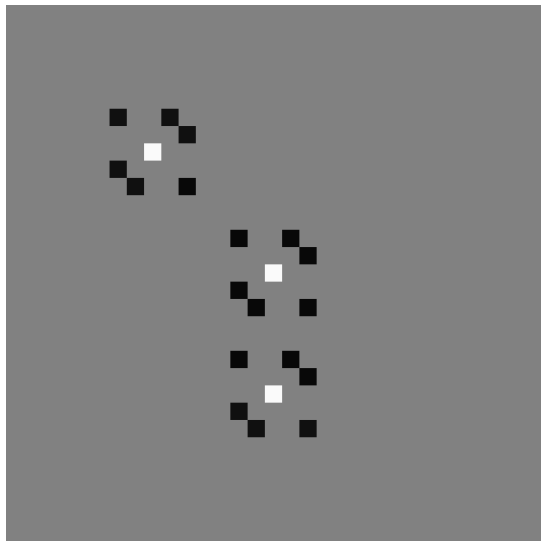
least squares

minimize:	$\varepsilon(x; O, C) = \sum C(a,b)(x(a) - x(b) - O(a,b))^2$
measurement:	$M = C \bullet O + (C \bullet O)'$
degree:	$D = \mathrm{Diag}((C + C')1)$
transition:	$P = D^{-1}(C + C')$
optimum:	$x^* = (I - P)^{-1} \cdot (D^{-1}M1)$

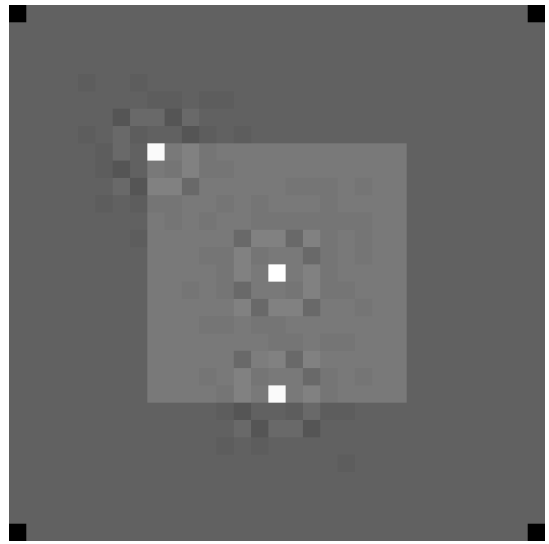
An Efficient and More Robust Integration Method



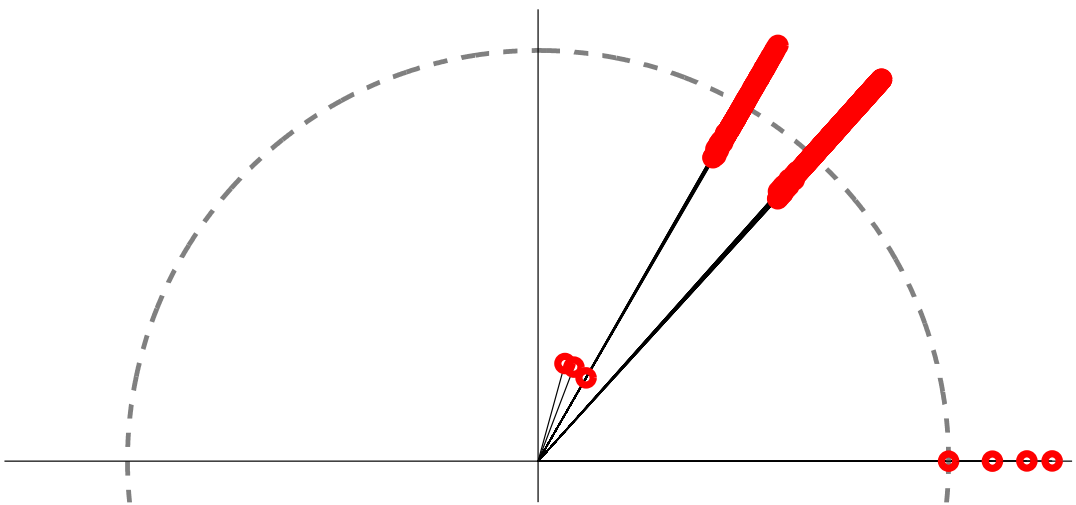
original image



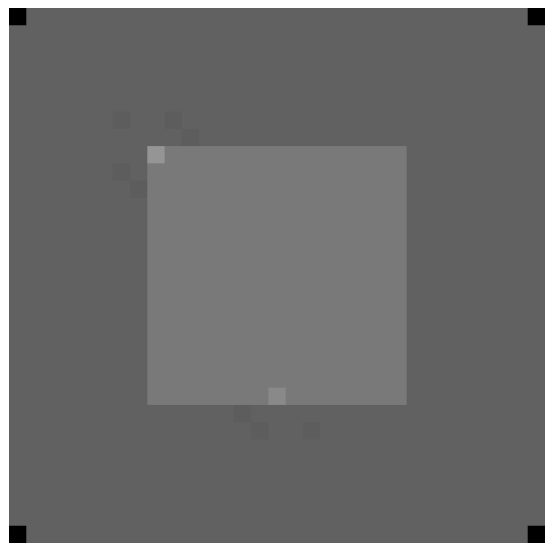
3×6 measurement outliers
neighbourhood radius $= 2$



LS optimum x^*

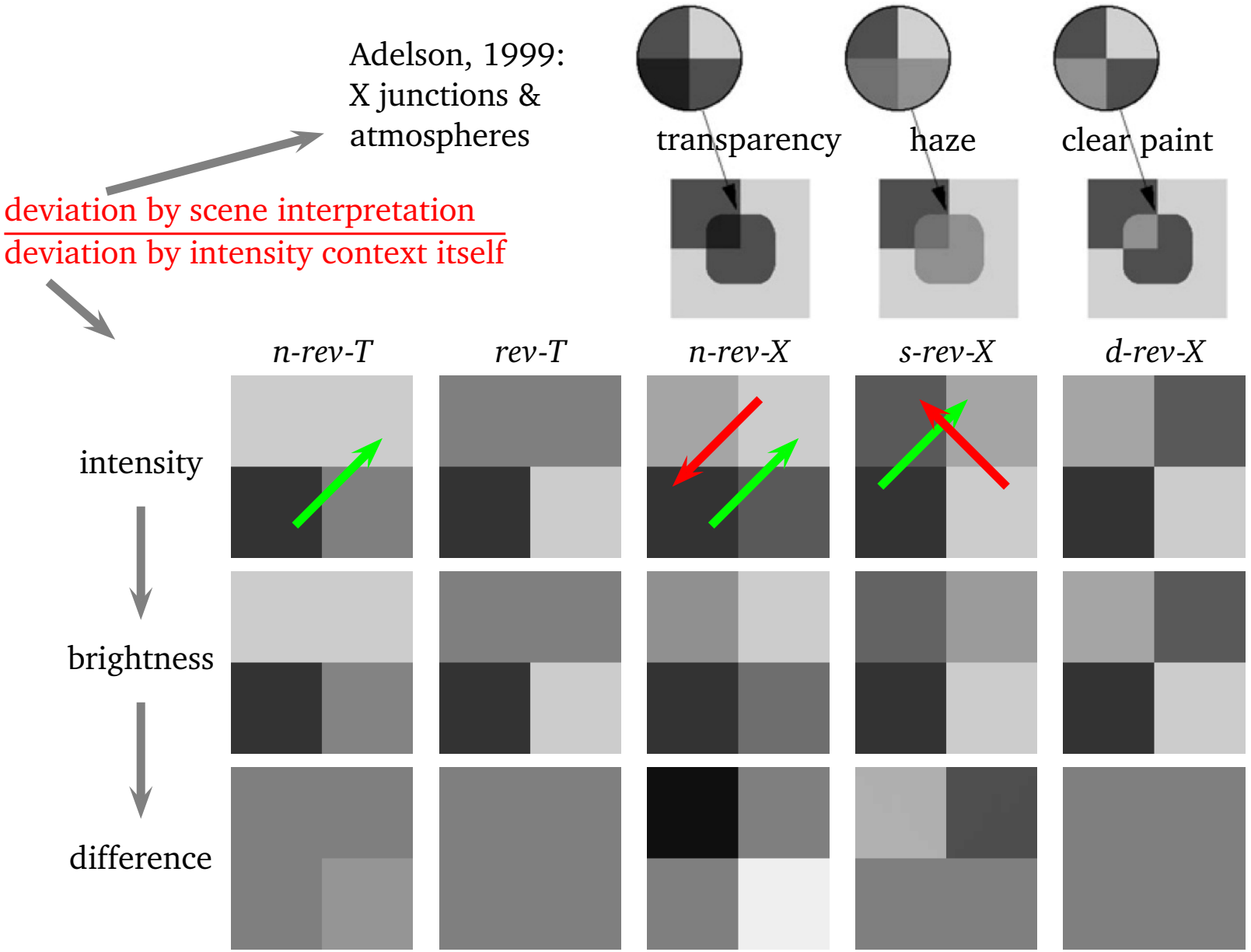


AE optimum z^*

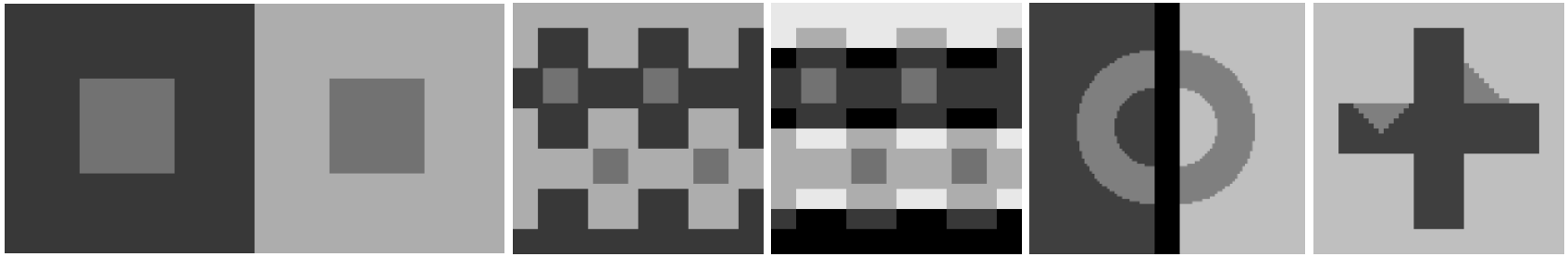


AE optimum θ^*

Brightness as Intensity Deviating along Gradient



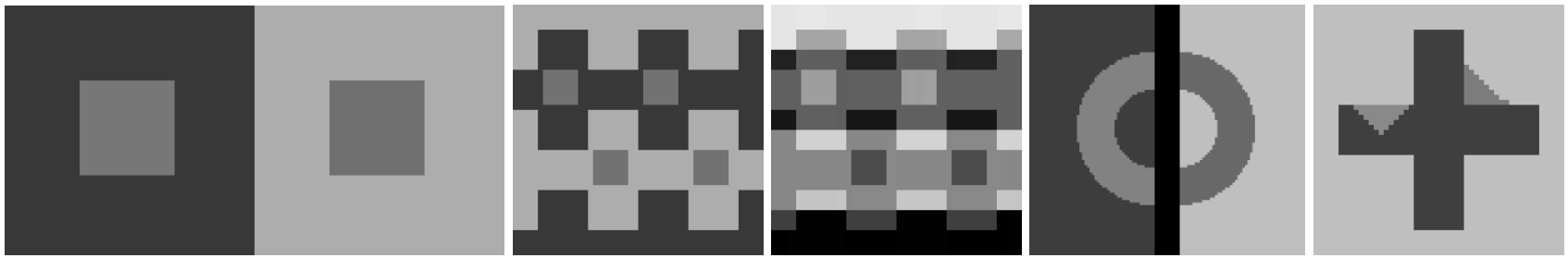
Brightness as Gestalt from Scale-Mixed Differences



input: objective intensity

$\Downarrow$

output: subjective brightness



brightness $-$ intensity

Simultaneous Contrast | Anti-Snake | Snake | Koffka Ring | Benary Cross