Generation of Precision Stimuli for Web-based and At-Home Psychophysics

Jeffrey B. Mulligan
NASA Ames Research Center

Banks/Schor lab meeting

November 4th, 2020

Environments for psychophysical testing

	Lab	Field
Gray scale resolution	10+ bits with hardware assist	8 bits
Frame rate	60-120+ FPS	60 FPS ?
Calibration options	Photometer Colorimeter Spectrophotometer Photodiode Camera	Human visual system Camera?

Environments for psychophysical testing

	Lab	Field
Gray scale resolution	10+ bits with hardware assist	More than 8 bits by integrating in space and time!
Frame rate	60-120+ FPS	60 FPS ?
Calibration options	Photometer Colorimeter Spectrophotometer Photodiode Camera	Human visual system Camera?

Part I: Improving intensity/color resolution by averaging in space and time

In space: halftoning, dithering

In time: temporal error diffusion

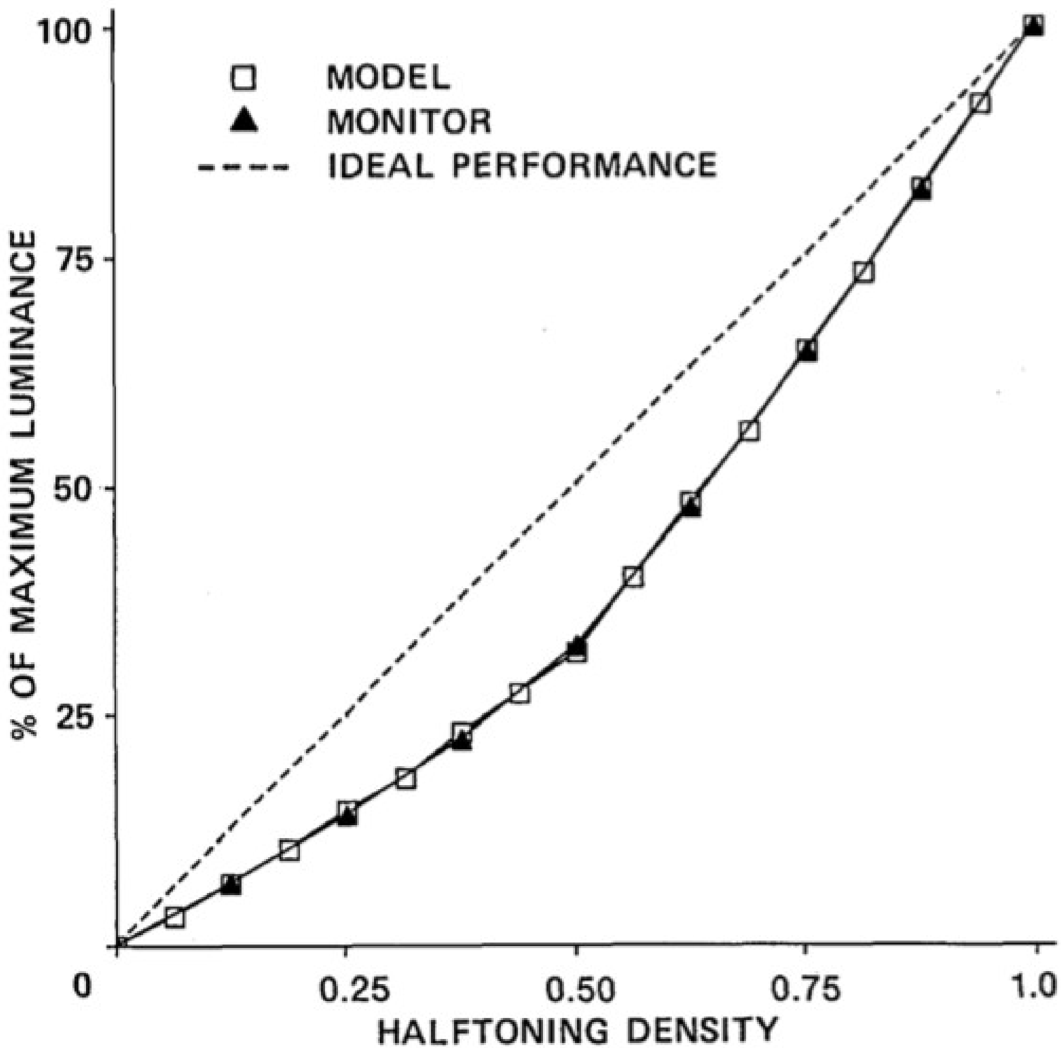
The adjacent pixel nonlinearity

- Halftoning approaches assume spatial independence

- Probably true for some/many/most displays now

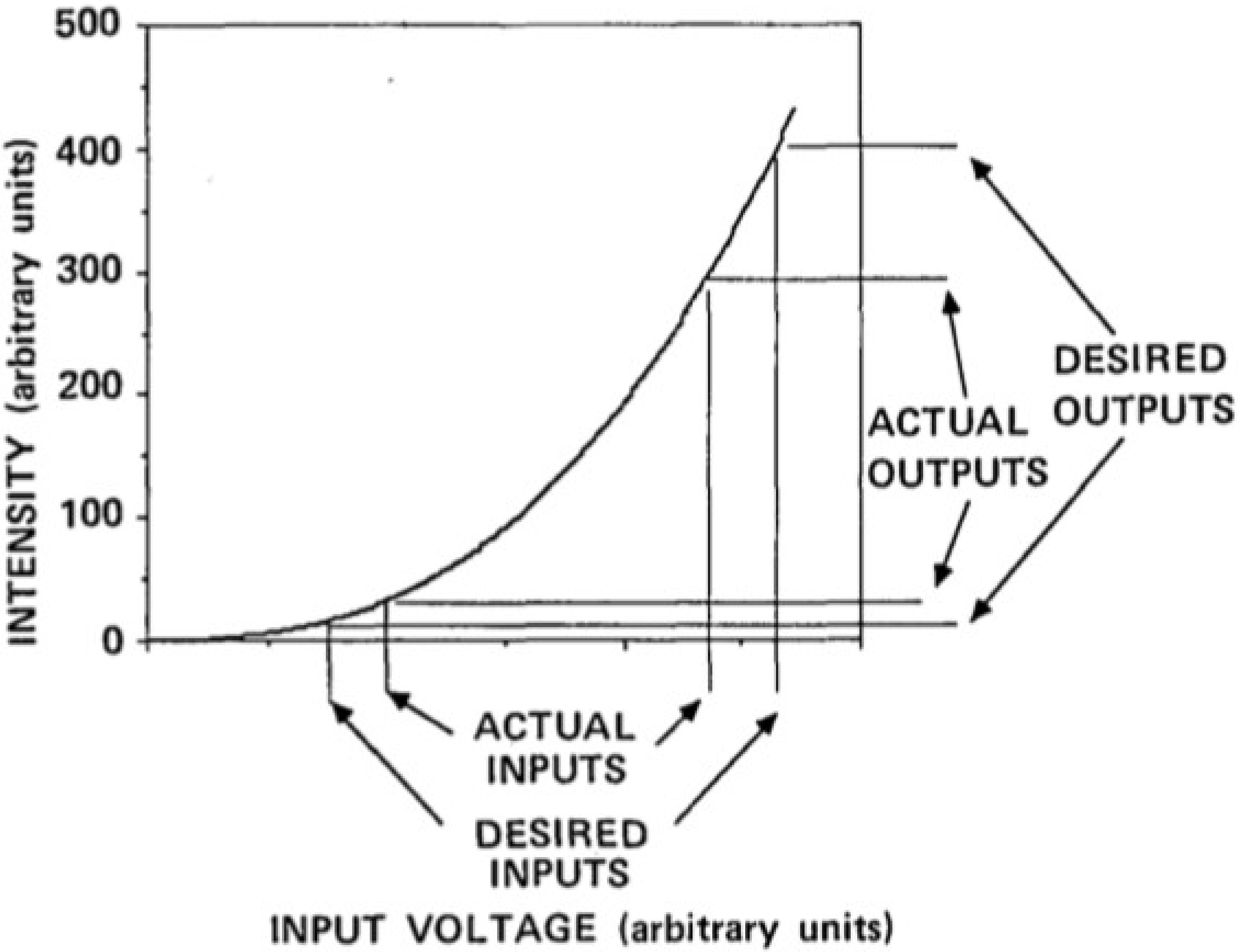
- Was NOT true for CRTs!

The adjacent pixel nonlinearity – measurements



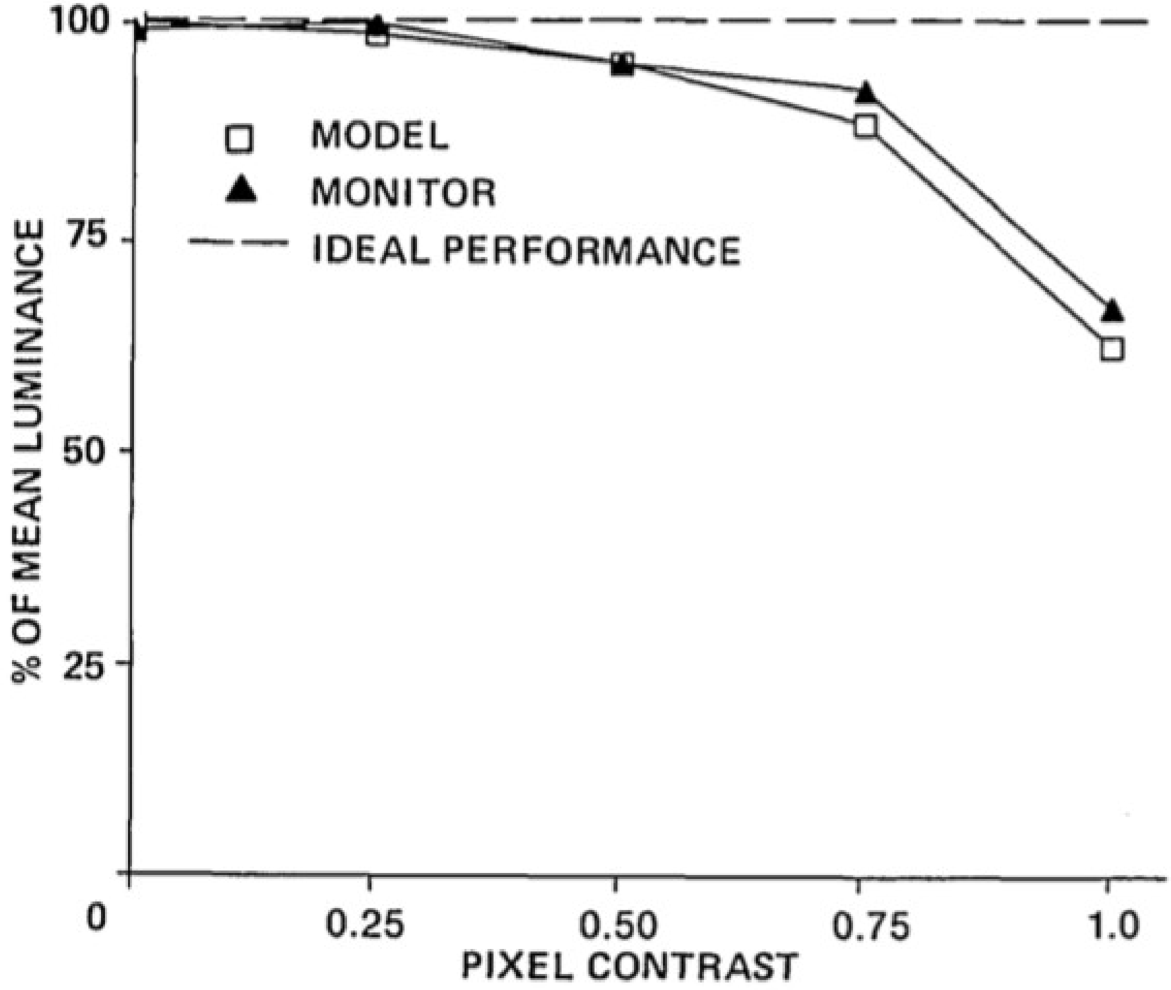
From Mulligan & Stone (1989)

The adjacent pixel nonlinearity – model



From Mulligan & Stone (1989)

The adjacent pixel nonlinearity – model predictions



From Mulligan & Stone (1989)

Halftoning (dithering)

Trades spatial resolution for intensity resolution
(relies on spatial integration)

Useful for precision stimuli as well as calibration

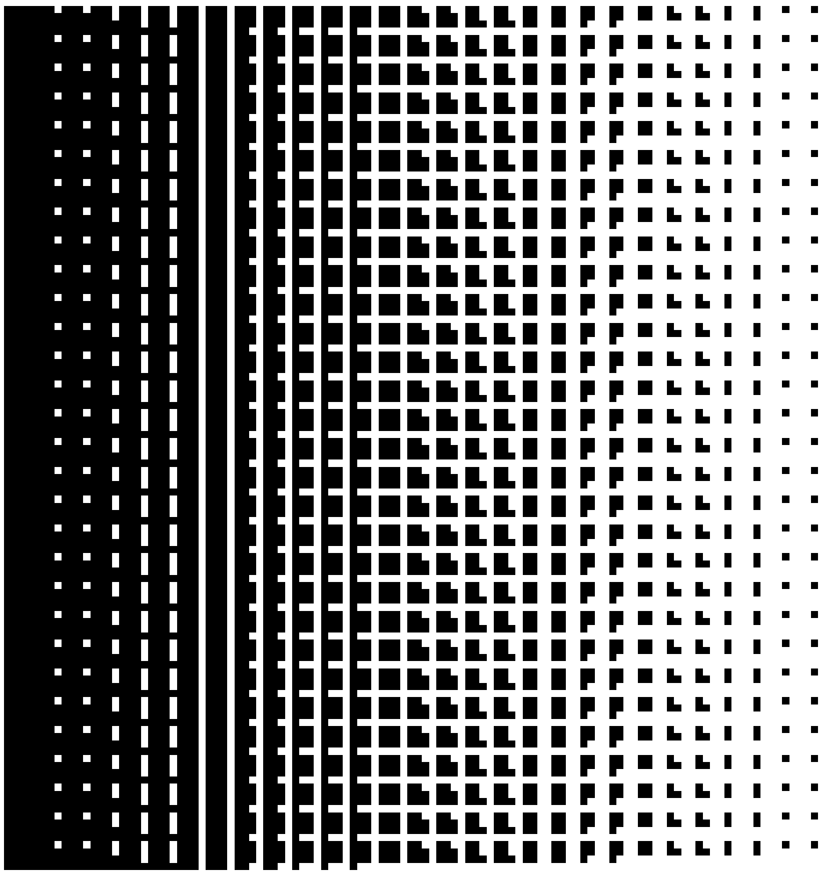
Methods:

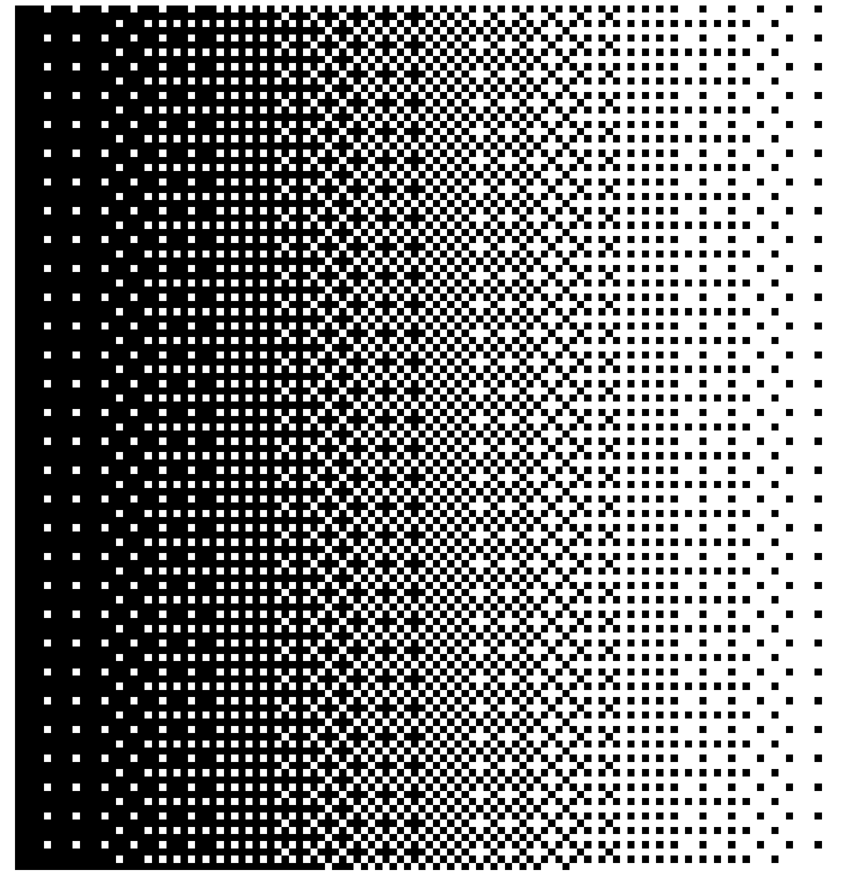
Ordered dither – fast, parallelizable, worst visual quality
Clustered dot – good for printing (ink spread)
Dispersed dot – good for displays (less visible noise)

Error diffusion – single pass, not parallelizable

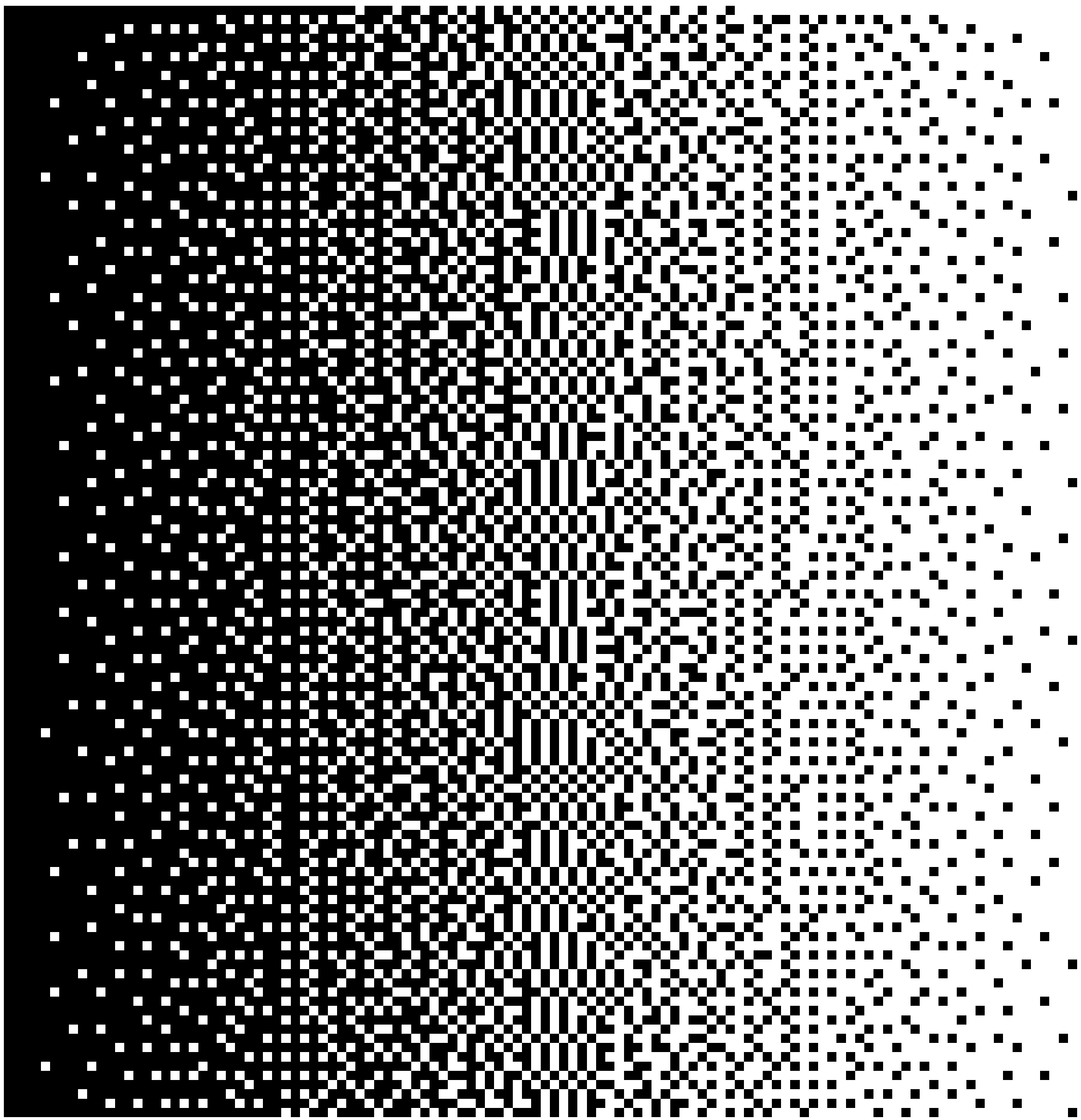
Visually optimized – iterative method, semi-parallelizable

Primitive halftoning: ordered dither



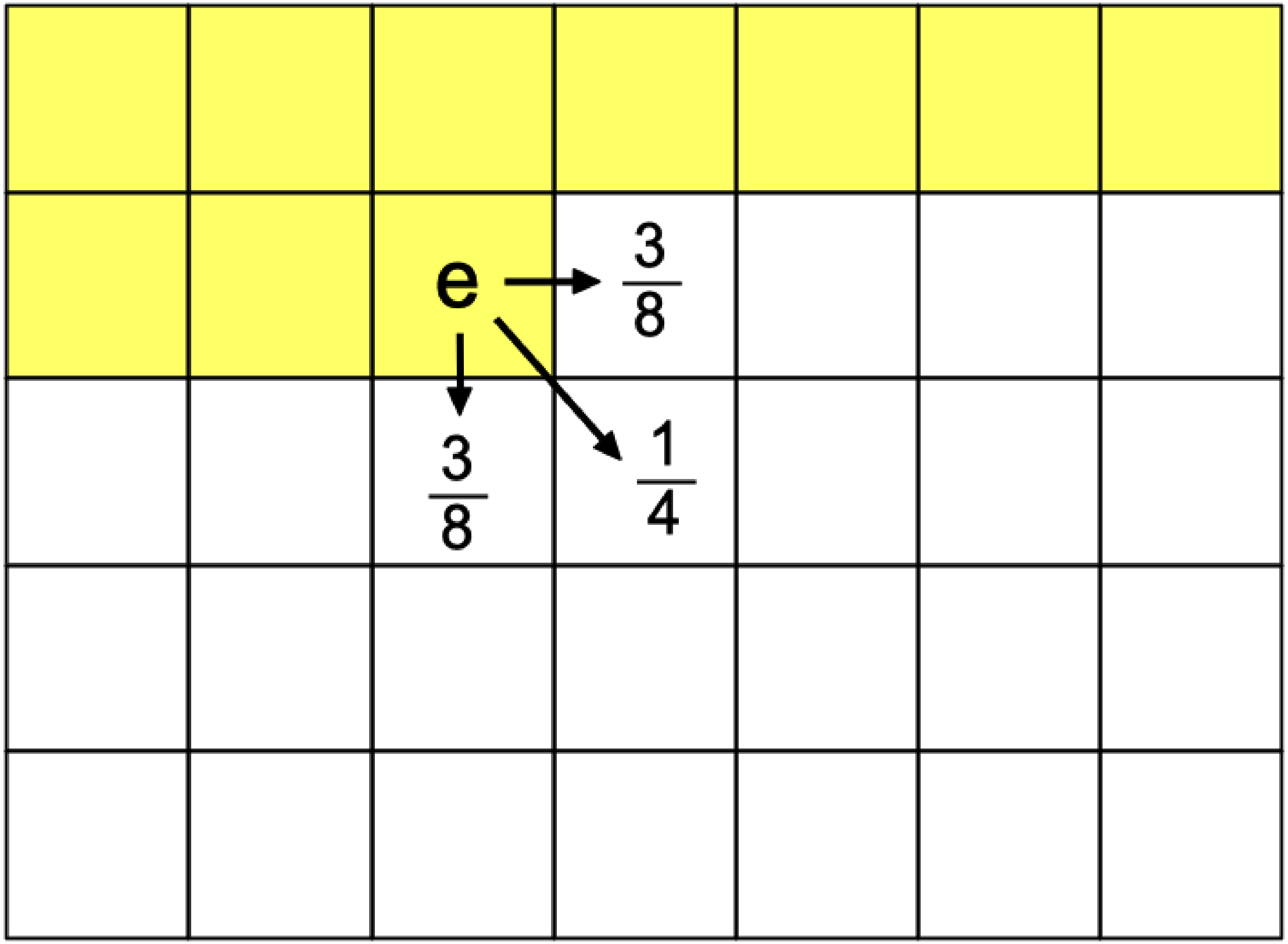


Better halftoning: Floyd-Steinberg error diffusion

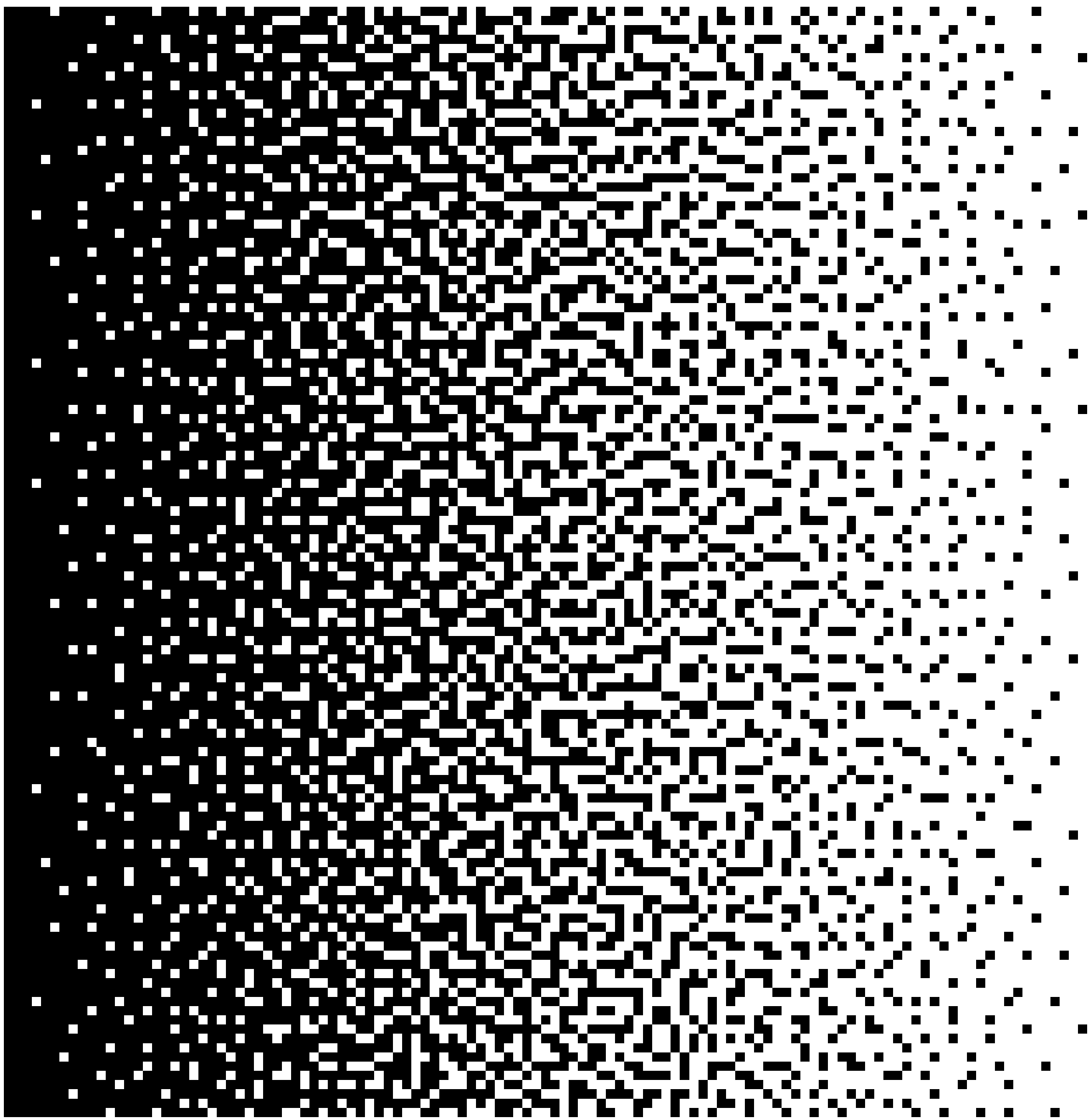


Modified Floyd-Steinberg algorithm as used in Mulligan & Stone (1989)

Floyd-Steinberg error diffusion weights



Best halftoning: visually optimized



Algorithm described in Mulligan & Ahumada (1992), included in QuIP open-source software distribution.

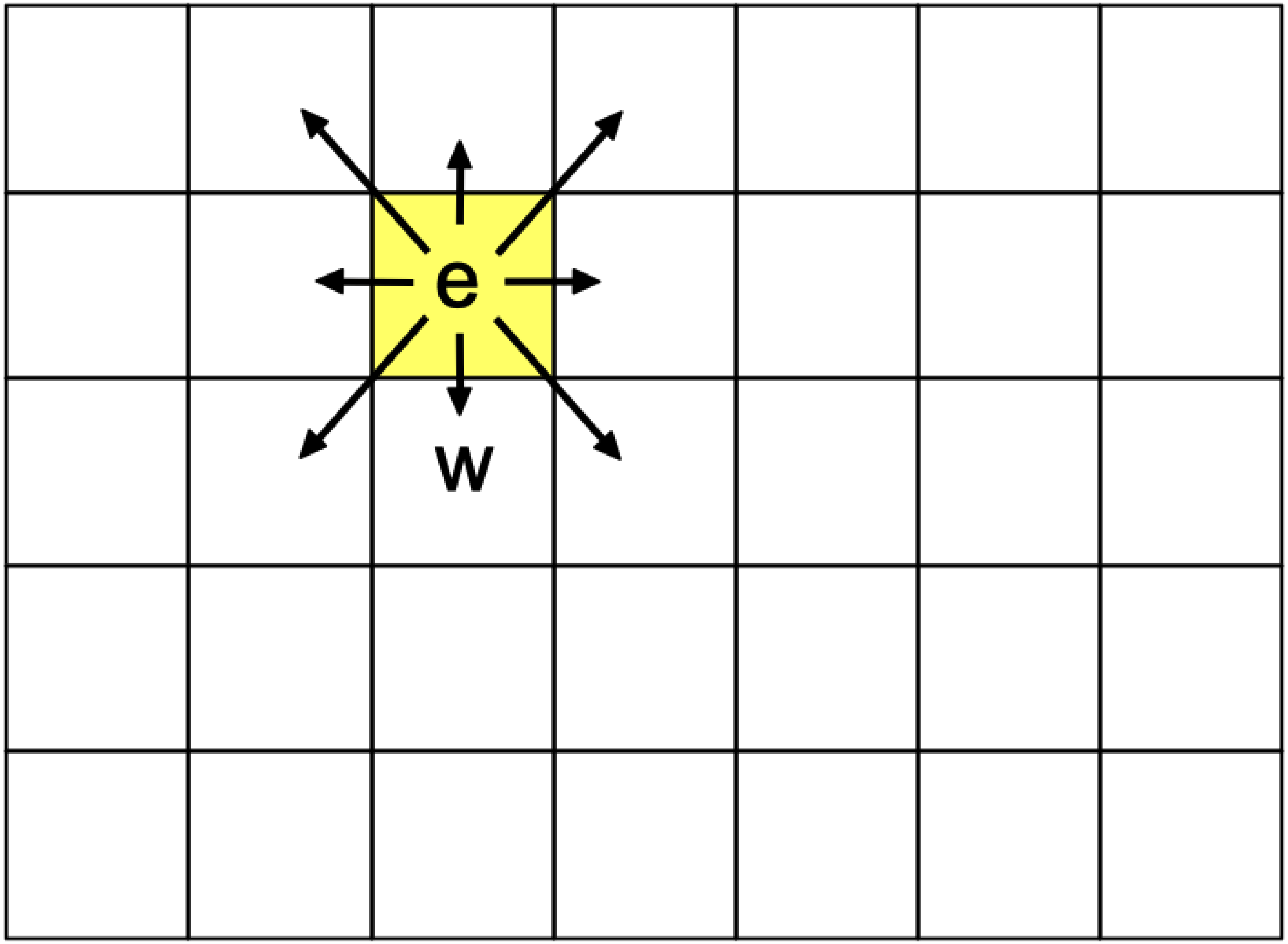
Method for visual optimization

Goal: minimize quantization error filtered by a visual (low-pass) filter

Result: goal can be achieved by diffusing errors with the filter in question.

Avoid local minima by “tunneling” (considering pixel pair exchanges in addition to pixel flips)

Error diffusion with non-causal filters



Generalization to color

Fact: chromatic channels have relatively poor spatial resolution

Can decompose RGB quantization error into luminance and chrominance components, and diffuse with different filters.

Improves luminance resolution by introducing (invisible) chrominance errors

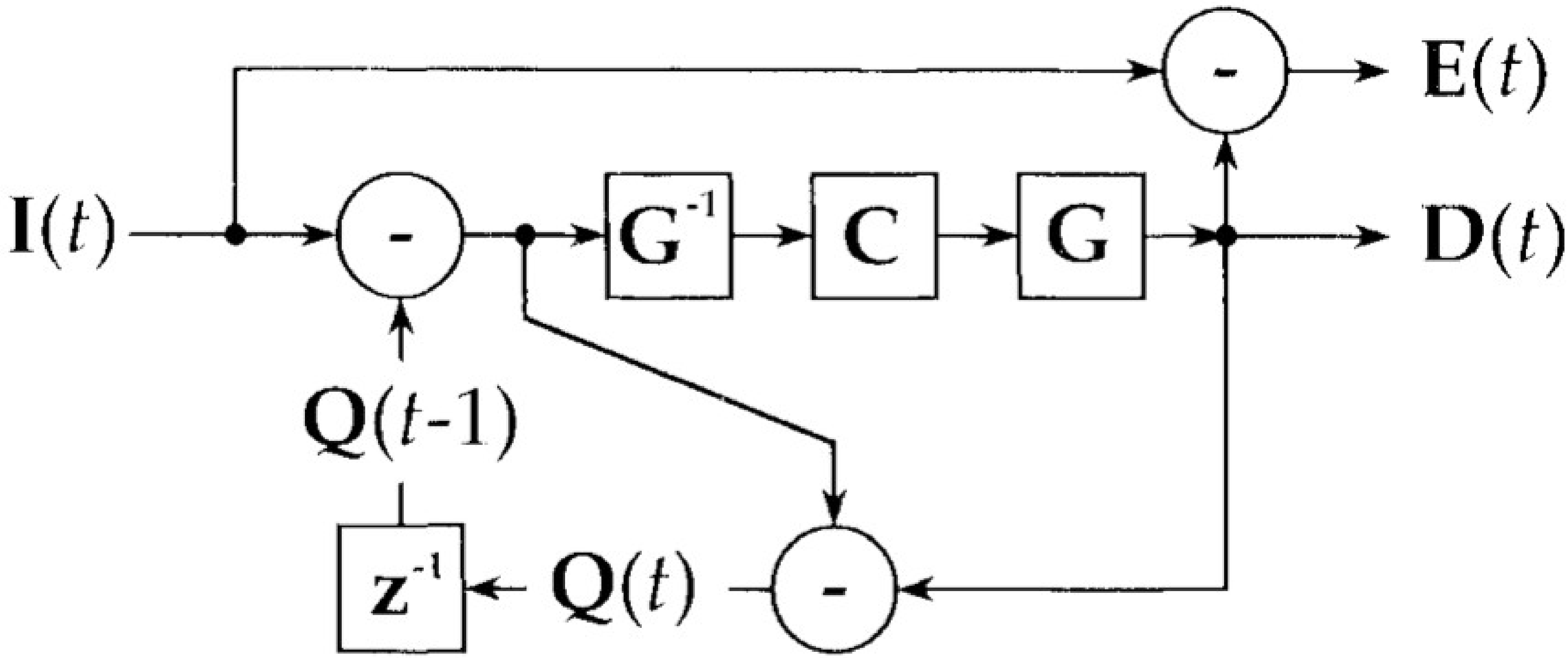
Related to Tyler's “bit stealing” method

Temporal error diffusion

For multi-frame stimuli, compute frame-wise quantization error and diffuse in time.

Applied to stimuli encoded as M-JPEG (Mulligan, 1997)

Temporal error diffusion



From Mulligan (1997)

Part II: Field Methods for Display Calibration

The fundamental principle: use the human as a null instrument (visual matching)

Example: gamma calibration by matching uniform fields to halftone patterns.

Find the setting corresponding to mid-gray by matching a 50-50 mixture of black and white.

Find additional settings by recursive bisection.

Inspiration from Anstis & Cavanagh (1983)

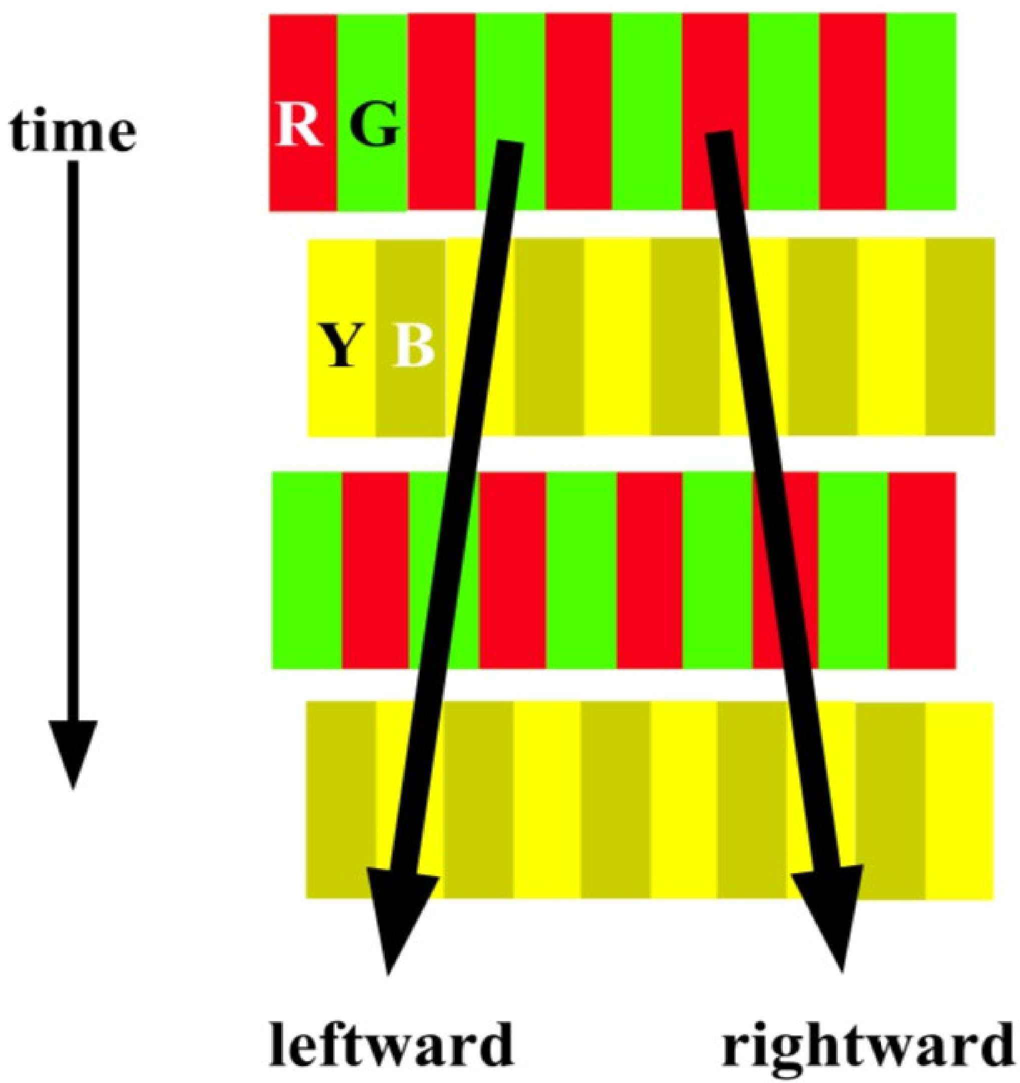


Figure from Mulligan (2009), after Anstis & Cavanagh (1983)

Inspiration from Anstis & Cavanagh (1983)

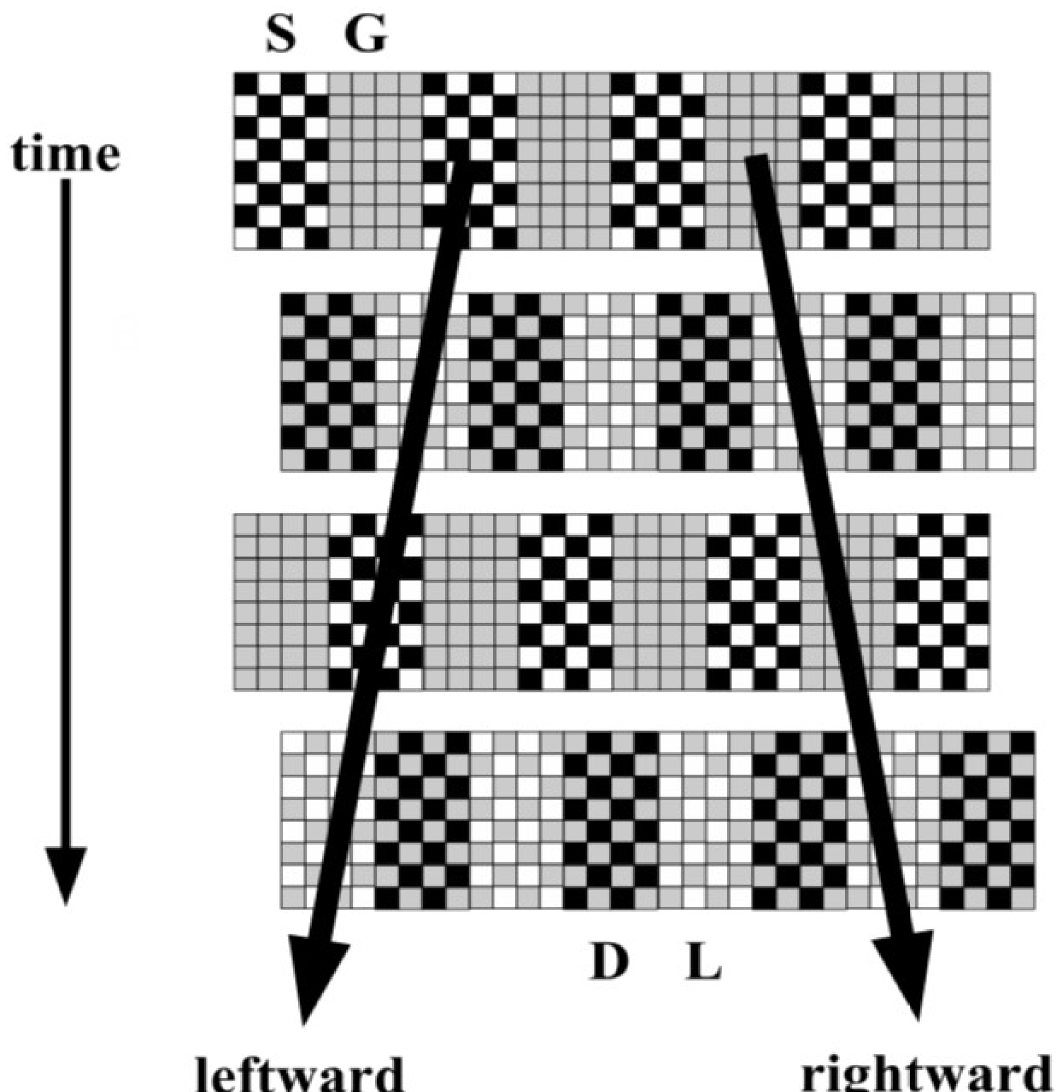
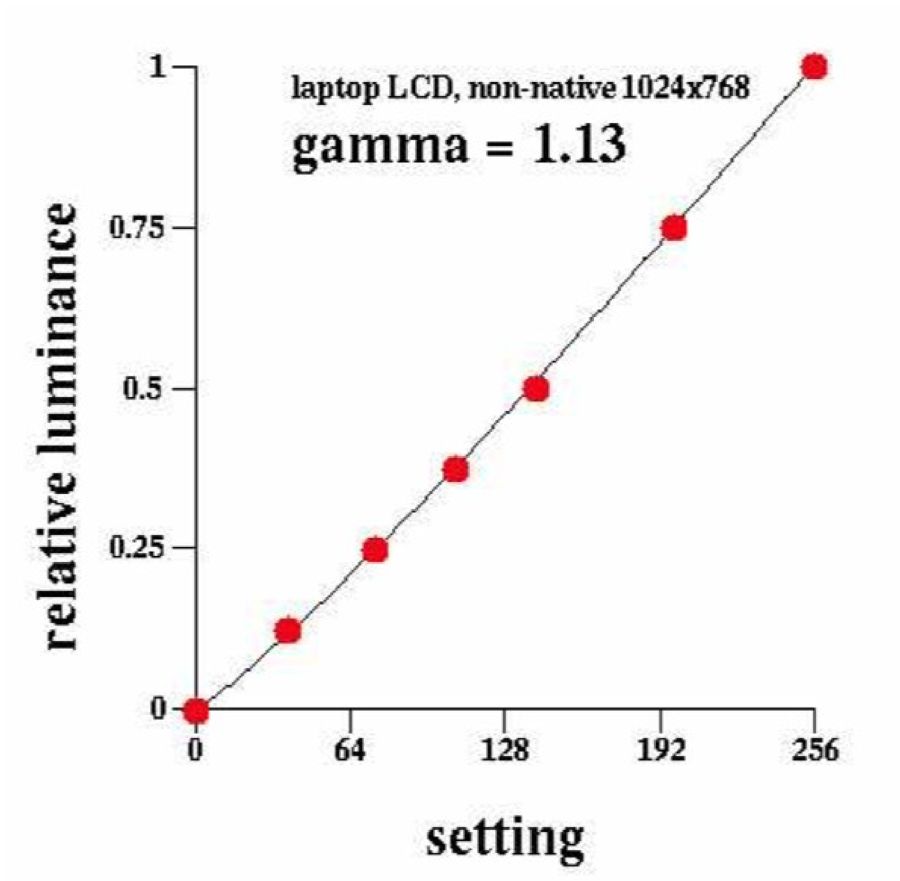


Figure from Mulligan (2009)

A curious, unexplained result



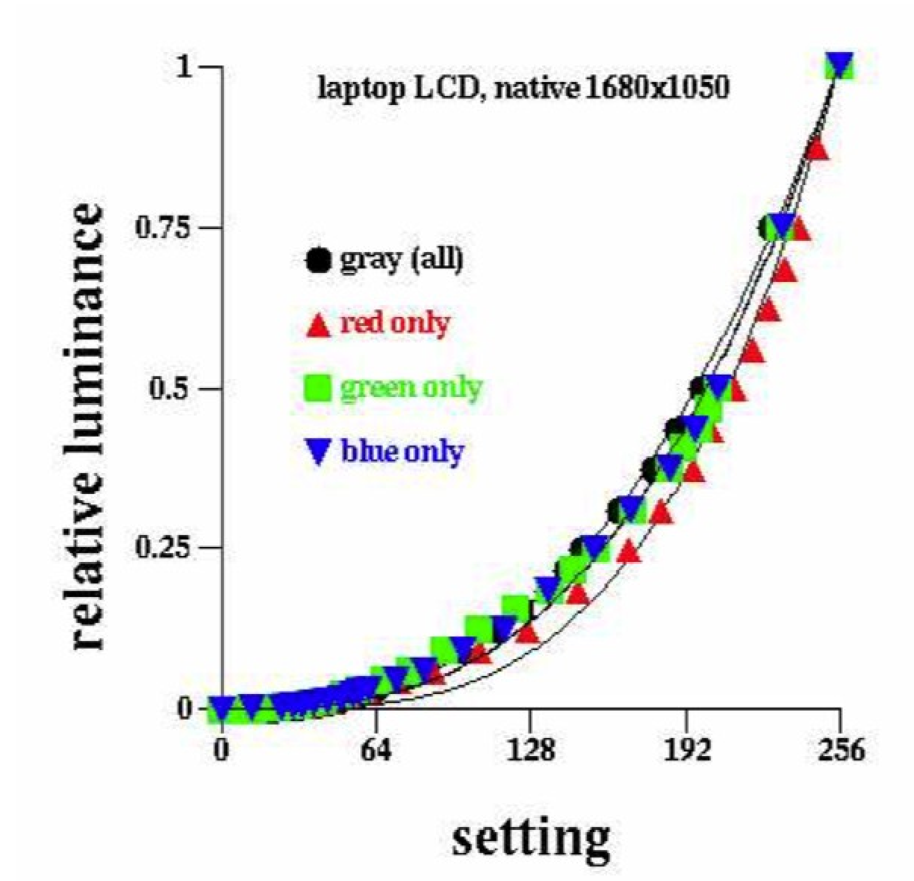


Figure from Mulligan (2009)

Another hardware oddity: iPod hysteresis

(measured with a photometer)

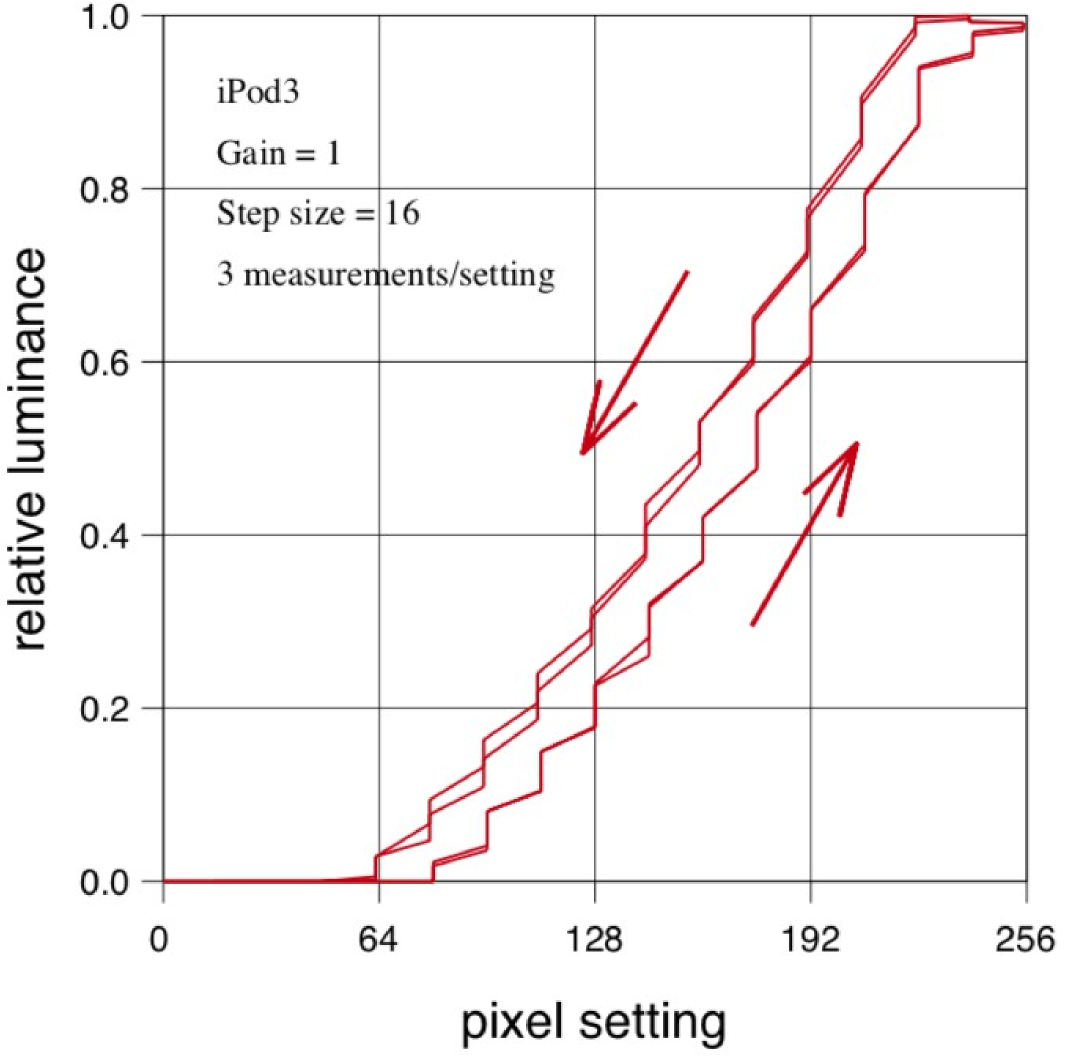
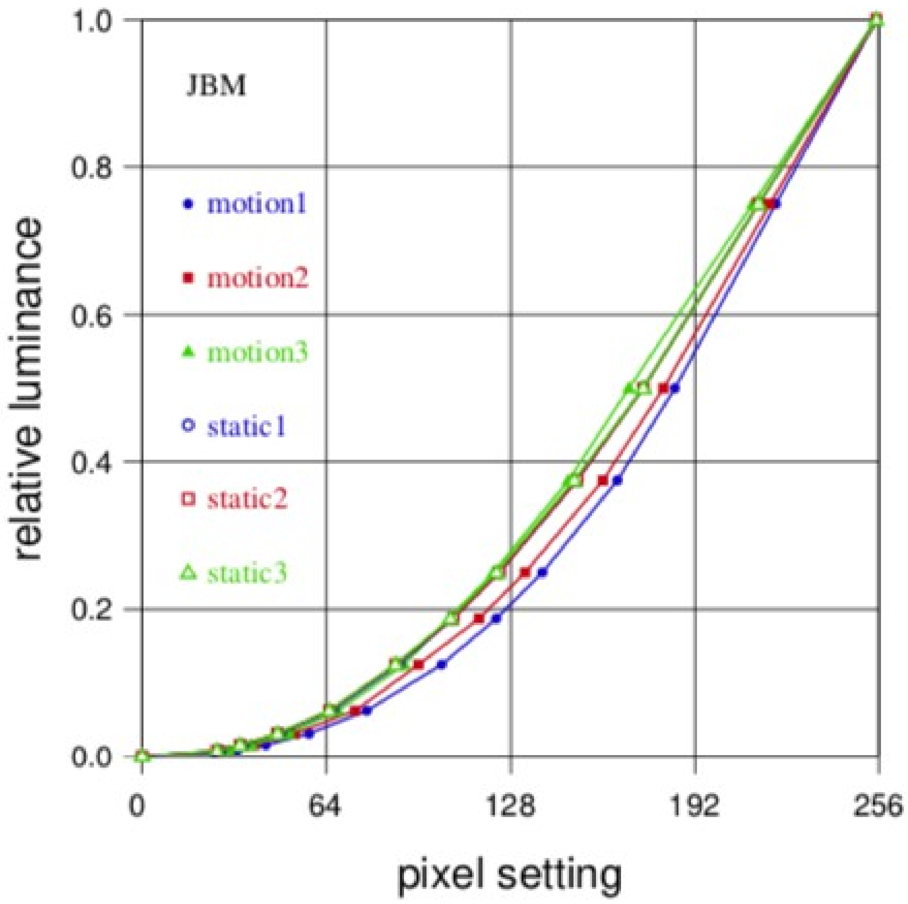


Figure from Mulligan (2015)

Differences between methods: static matching vs. motion nulling (iPod 3)



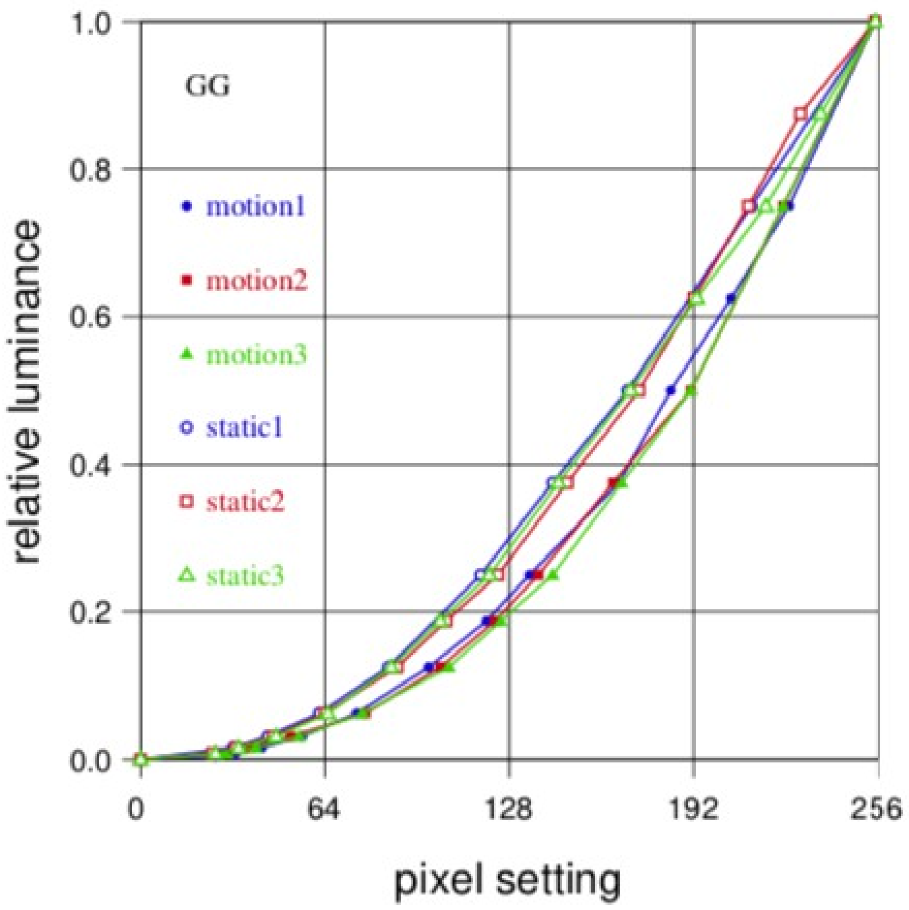


Figure from Mulligan (2016)

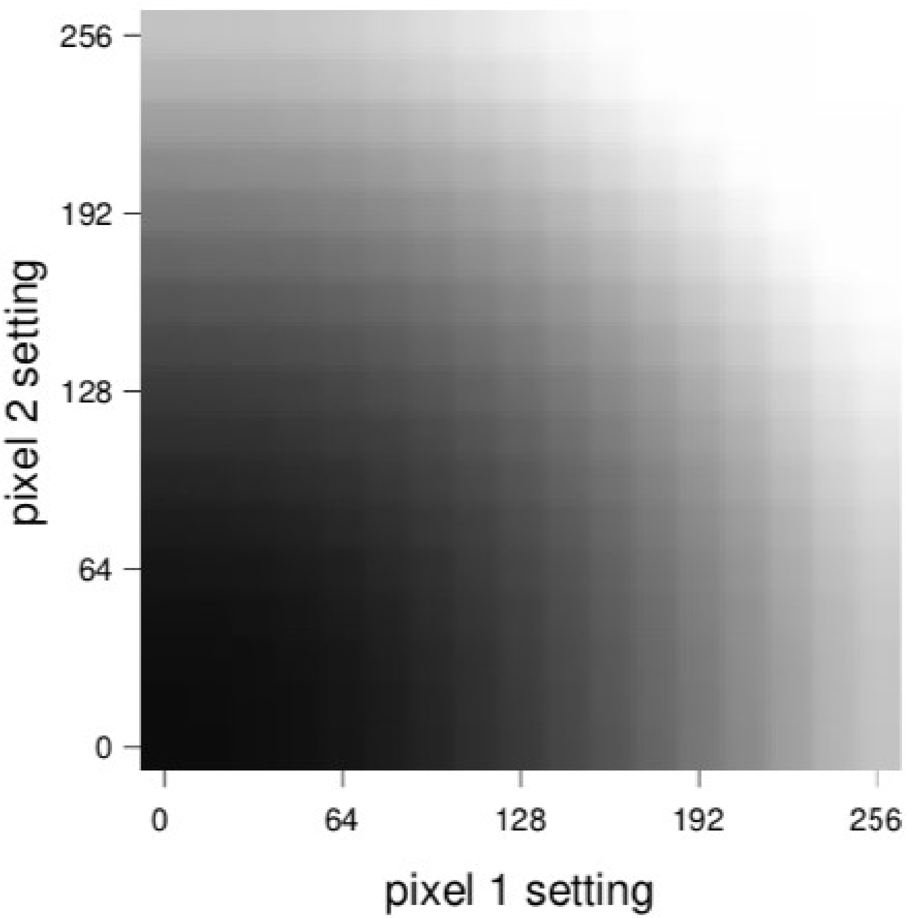
What about using a camera?

Cameras have gamma too!

Can't calibrate the camera with a uniform display patch due to the ***exponential ambiguity*** (Mitsunaga & Nayar, CVPR 1999; Grossberg & Nayar, IEEE Trans. PAMI, 2003)

Solution: hybrid patches combined with camera defocus allow simultaneous joint recovery of camera and display gamma functions

Camera vs. psychophysics



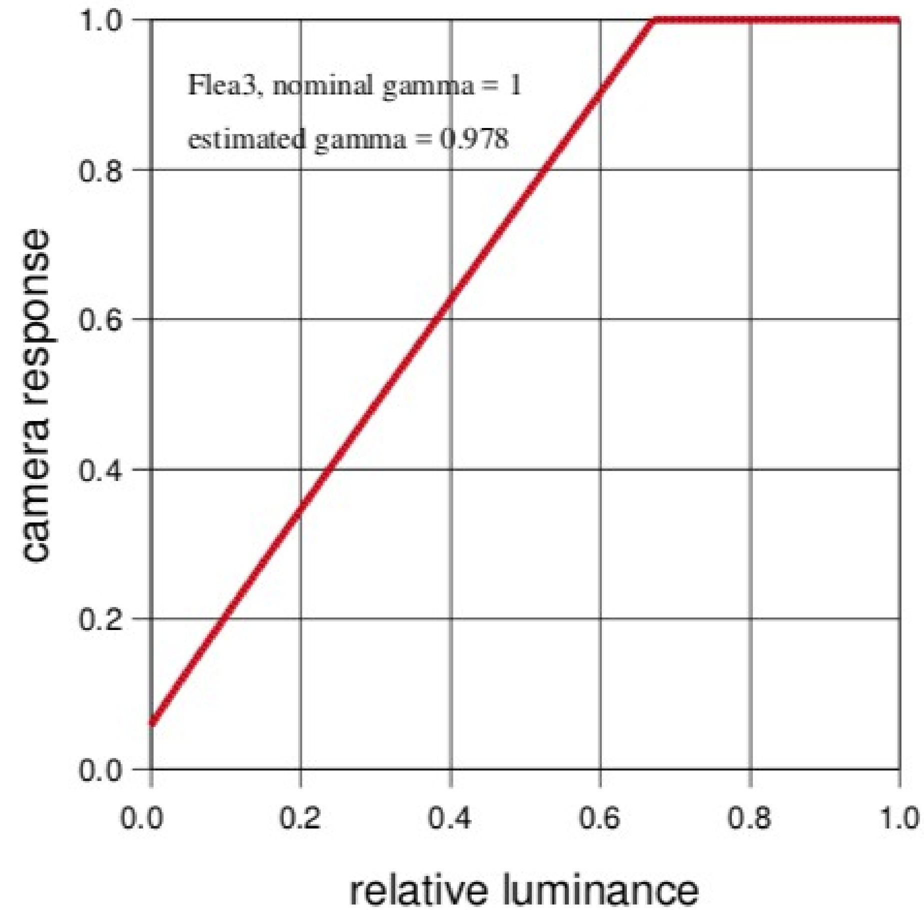


Figure from Mulligan (2016)

Camera vs. psychophysics

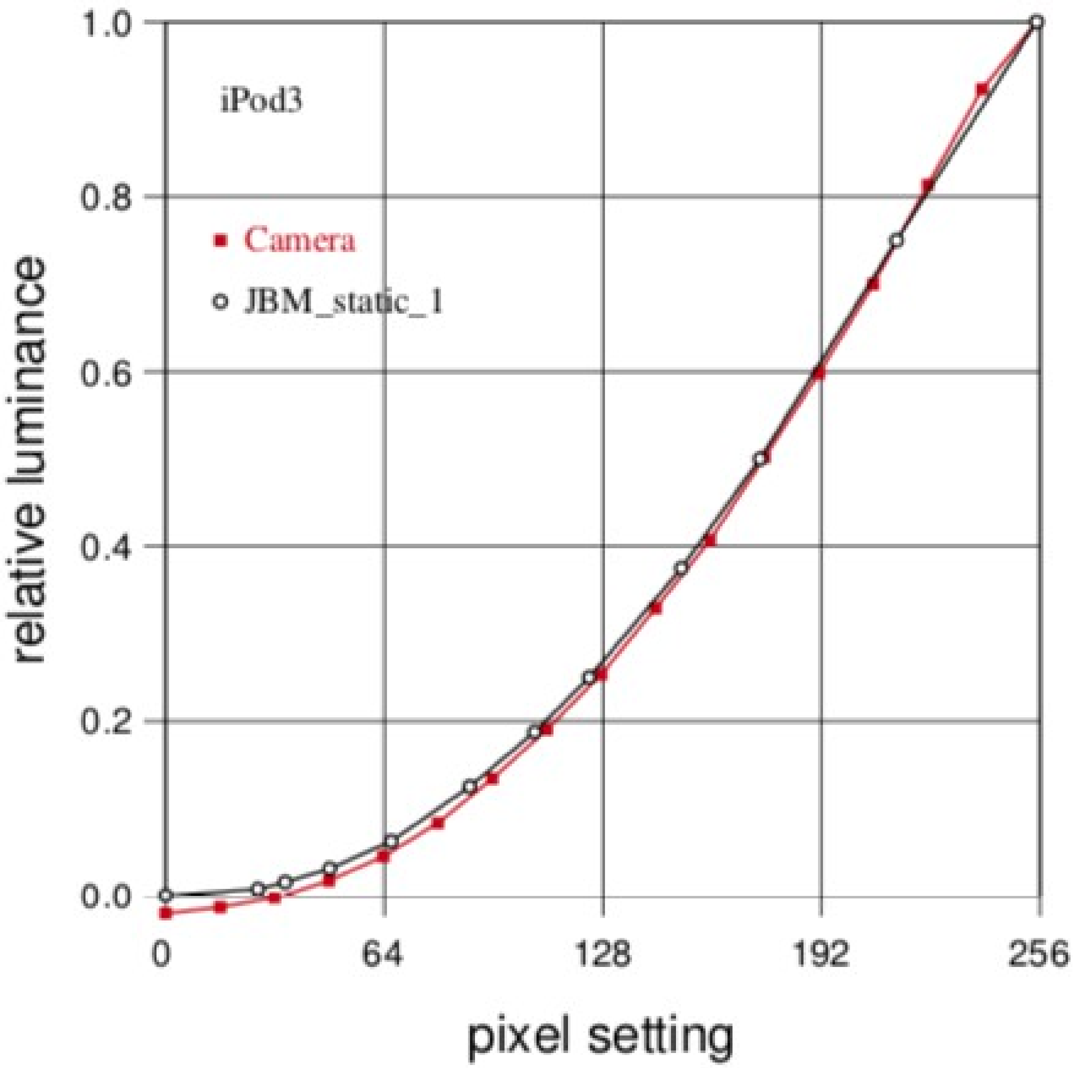


Figure from Mulligan (2016)

What about color?

Image from Mulligan (2009)

Where to read more:

Mulligan, J. B., and Stone, L. S. (1989). "Halftoning method for the generation of motion stimuli." *J. Opt. Soc. Am. A*, **6**(8), pp. 1217-1227.

Mulligan, J. B., and Ahumada, A. J. Jr. (1992). "Principled halftoning based on human vision models," in Rogowitz, B. E. (ed.), *Human Vision, Visual Processing, and Visual Display III*, *Proc. SPIE,* v. **1666**, pp. 109-121.

Mulligan, J. B., and Ahumada, A. J. Jr. (1992). "Principled methods for color dithering based on models of the human visual system." Proc. SID Int. Symp. Dig. Tech. Papers, v. **23**, pp. 194-197.

Mulligan, J. B. (1997). "Application of M-JPEG compression hardware to dynamic stimulus production." *Spatial Vision*, v. **11**(1), pp. 19-32.

Where to read even more:

Mulligan, J. B. (2009). “Presentation of calibrated images on the web.” in Rogowitz, B. E. and Pappas, T. N. (eds.), *Human Vision and Electronic Imaging XIV, Proc. SPIE*, v. **7240**.

Mulligan, J. B. (2015). “Psychophysical calibration of mobile touch-screens for vision testing in the field.” Poster presented at the annual meeting of the Vision Sciences Society (VSS).

Mulligan, J. B. (2016). “A method for rapid measurement of contrast sensitivity on mobile touch-screens.” in Rogowitz, B. E. Pappas, T. N., and de Ridder, H. (eds.), *Human Vision and Electronic Imaging 2016, IS&T Intl. Symp. on Electronic Imaging 2016*, pp. HVEI-104.1 – HVEI-104.6.

Mulligan, J. B. (2020). “Evaluation of tablet-based methods for assessment of contrast sensitivity.” *Proc. Human Vision and Electronic Imaging 2020, IS&T Intl. Symp. on Electronic Imaging 2020*, pp. 210-1 - 210-7.

For more information:

jeffrey.b.mulligan@nasa.gov

https://hsi.arc.nasa.gov/groups/scanpath/publications.php

Thanks for your attention!