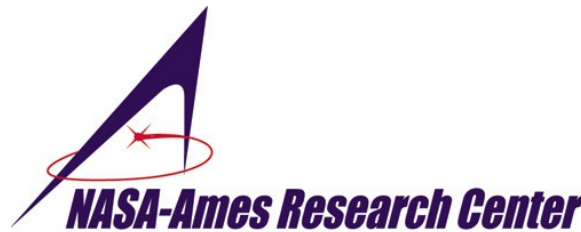


Methods for Calibrating a Display Without a Photometer

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OSA Technical Group Special Webinar:
Display Calibration for Internet and At-home Human Vision
Visual Perception and Color Research

August 26th, 2020

Where to read more (if I run out of time):

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. (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.

The fundamental principle:

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.

The fundamental principle:

the human as a null instrument (visual matching)

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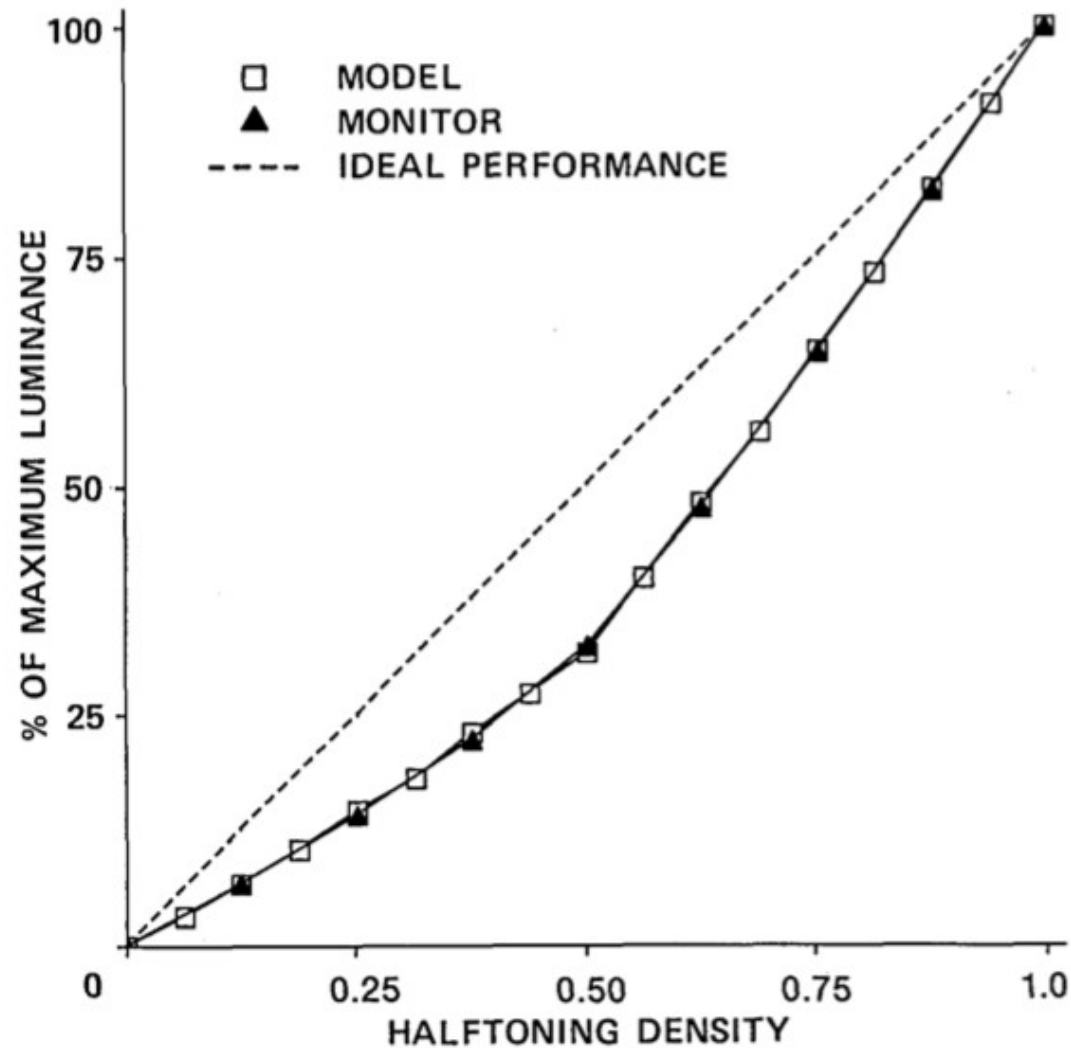
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The adjacent pixel nonlinearity

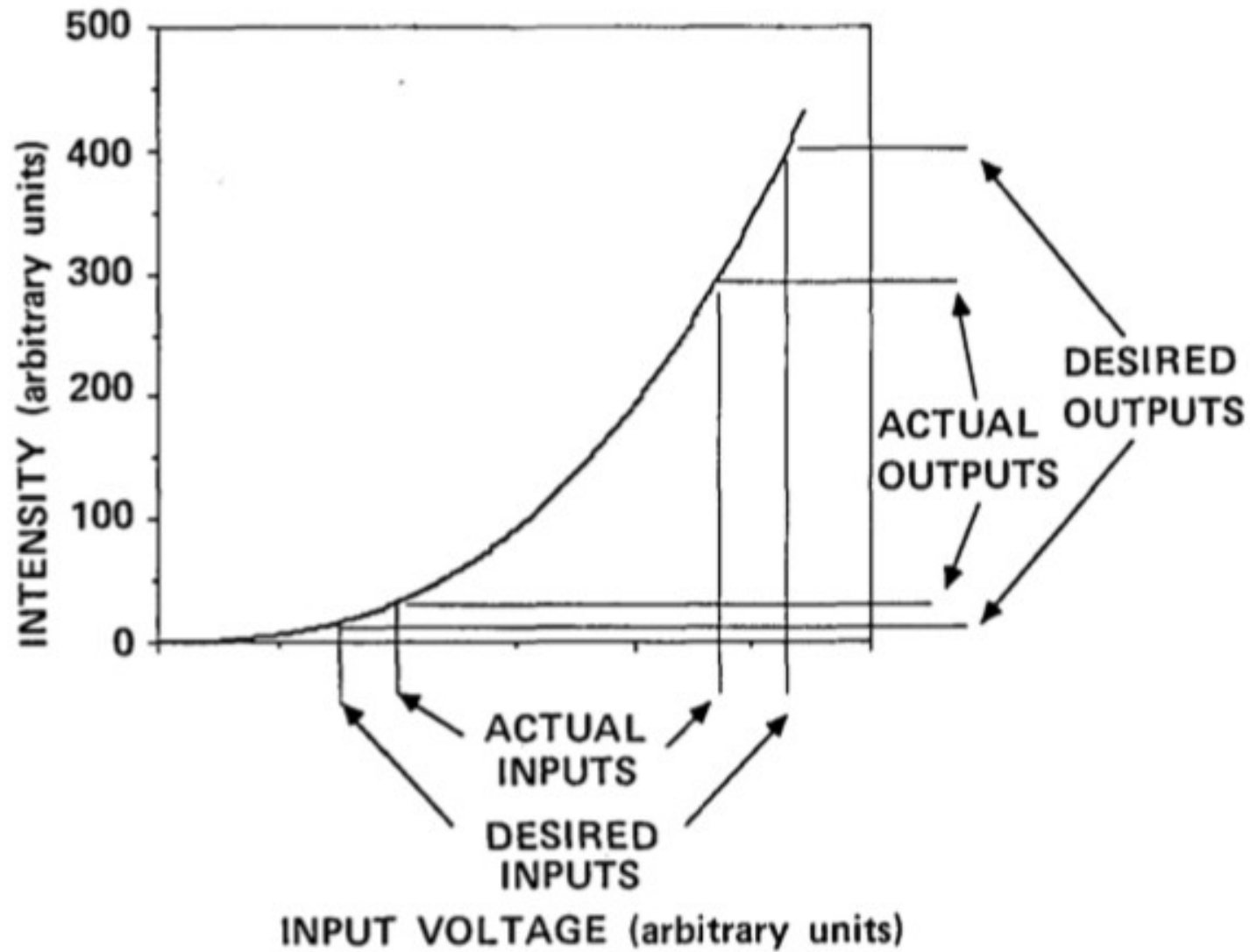
- Halftoning approaches assume spatial independence
- Probably true for some/many/most displays now
- Was NOT true for CRTs!

The adjacent pixel nonlinearity – measurements



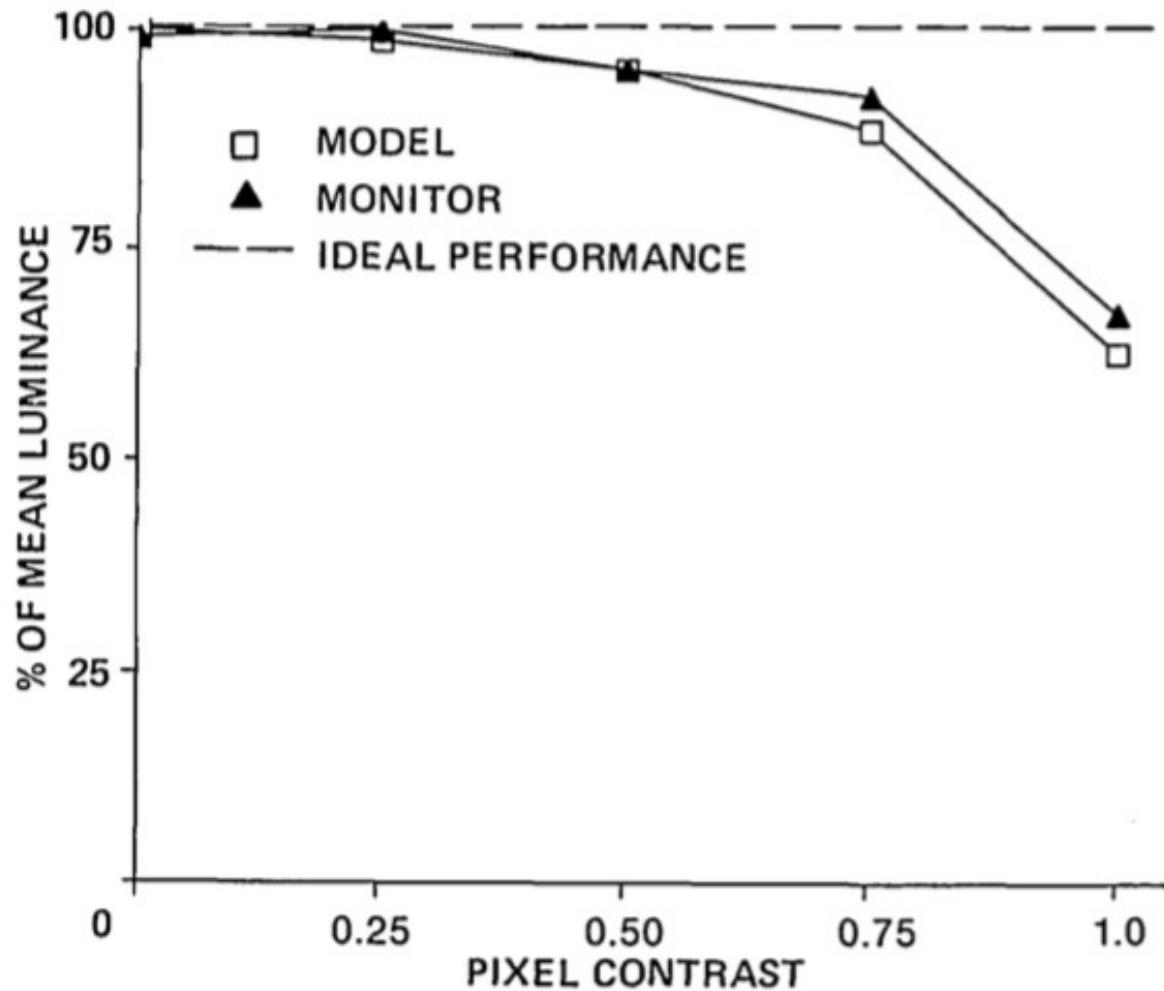
From Mulligan & Stone (1989)

The adjacent pixel nonlinearity – model



From Mulligan & Stone (1989)

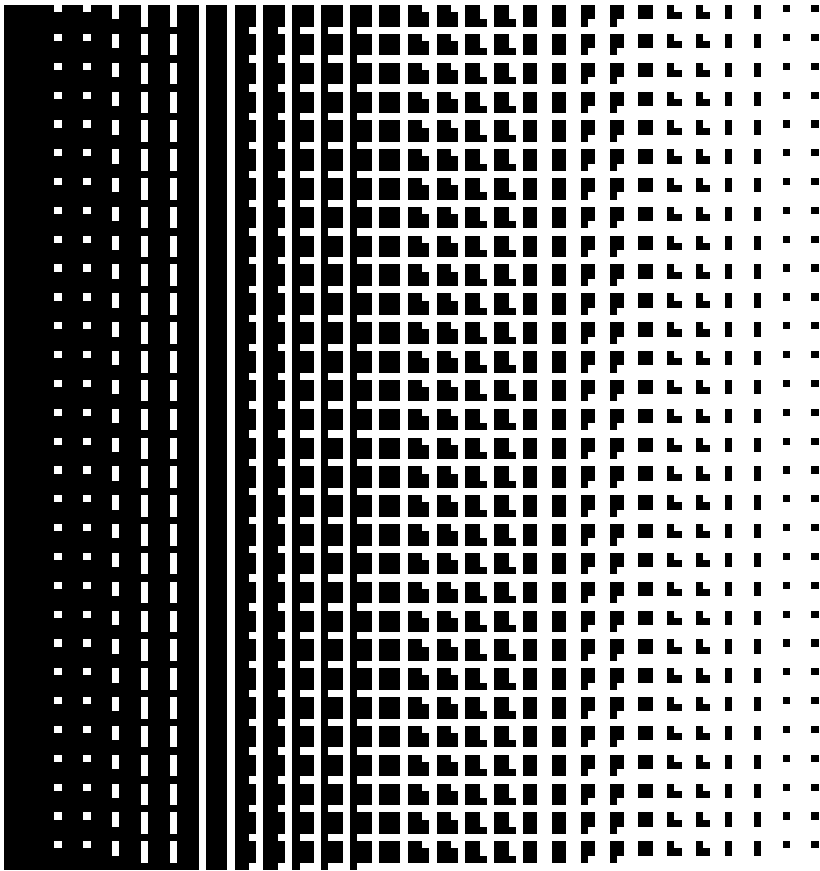
The adjacent pixel nonlinearity – model predictions



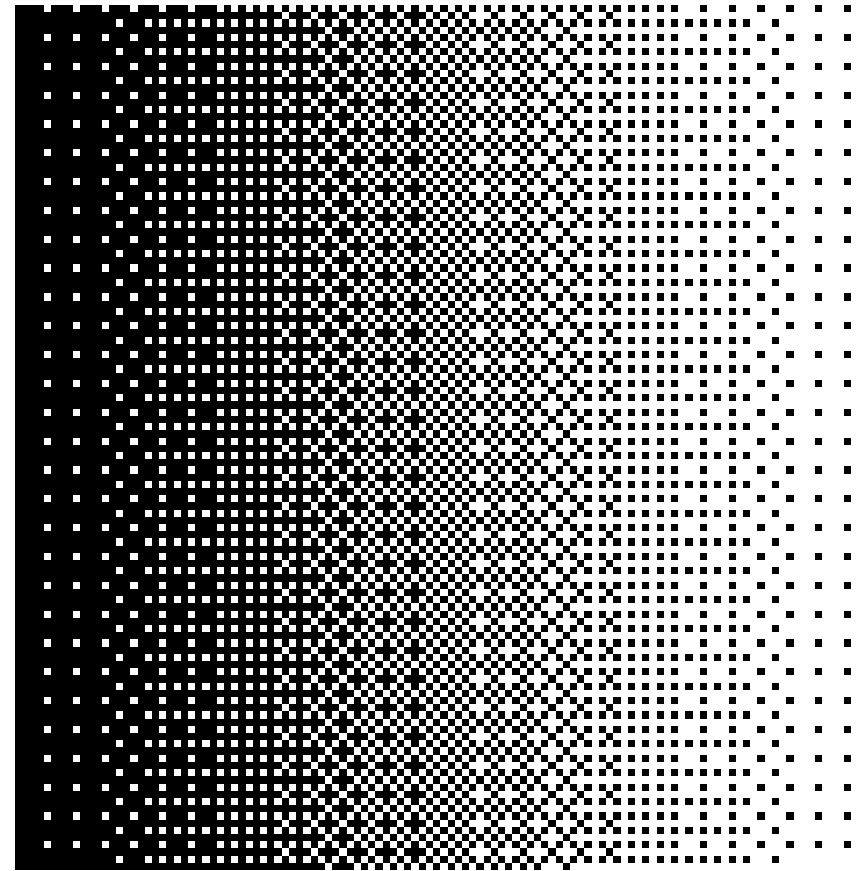
From Mulligan & Stone (1989)

Primitive halftoning: ordered dither

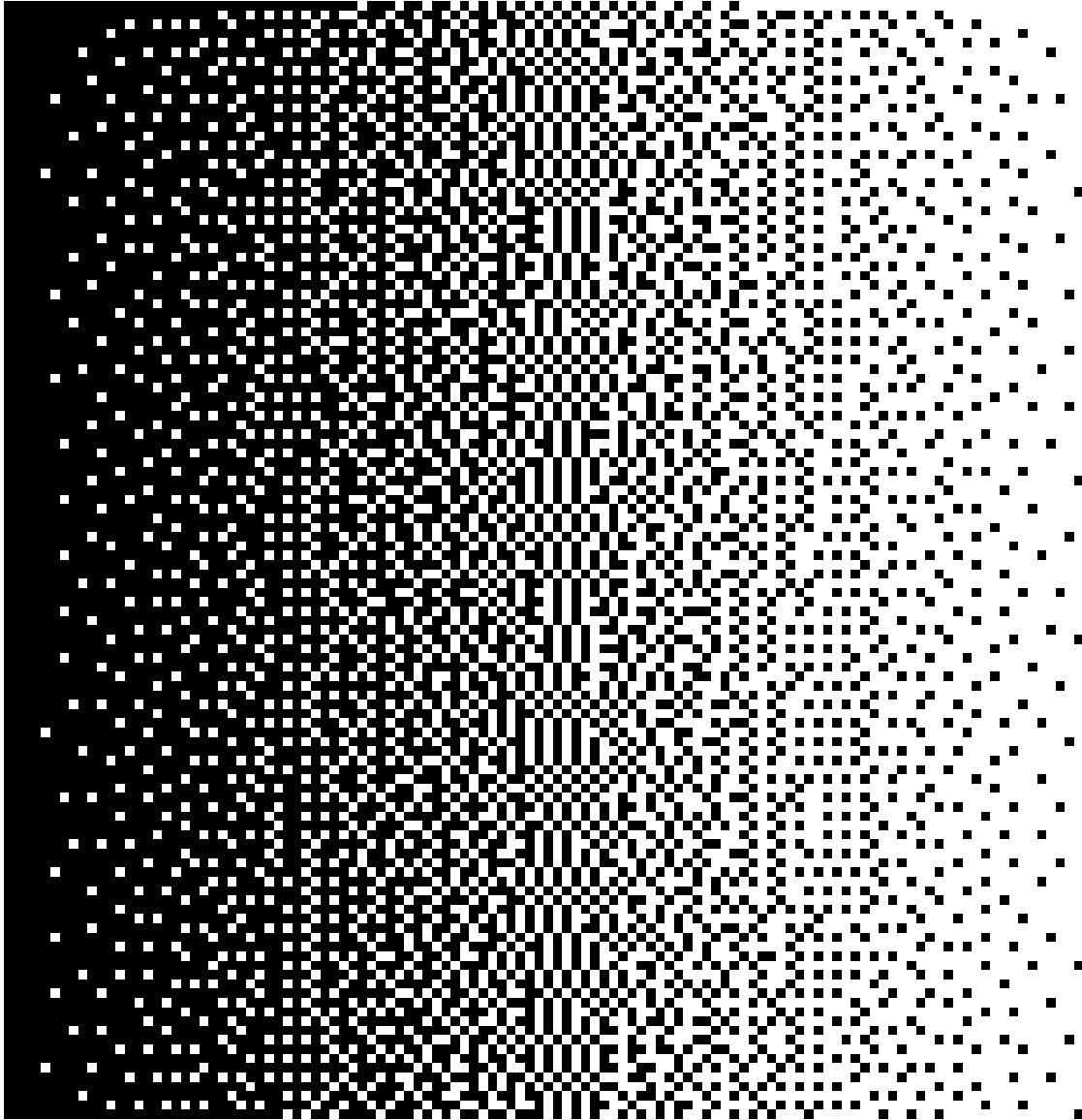
clustered dot



dispersed dot

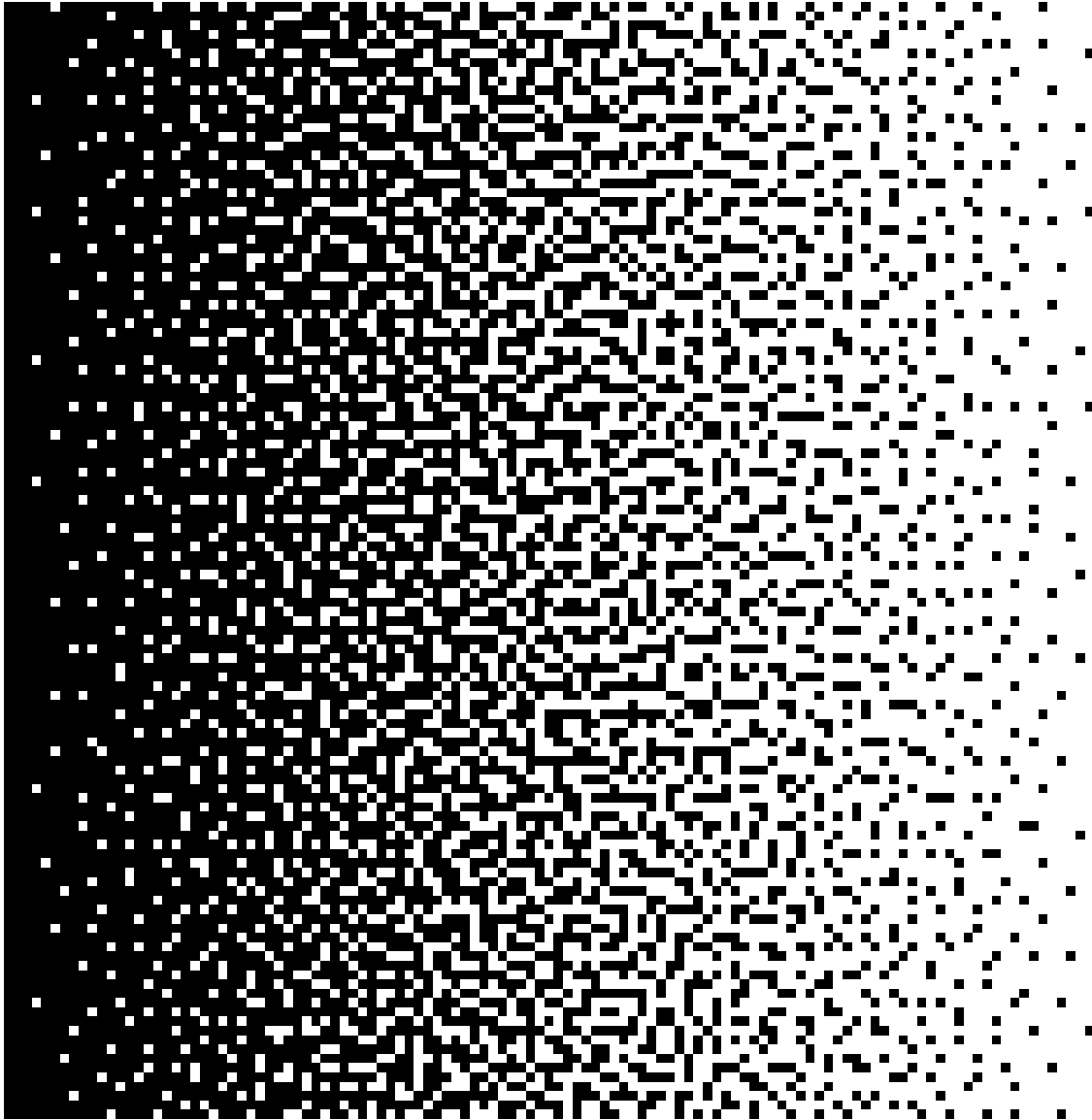


Better halftoning: Floyd-Steinberg error diffusion



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

Best halftoning: visually optimized



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

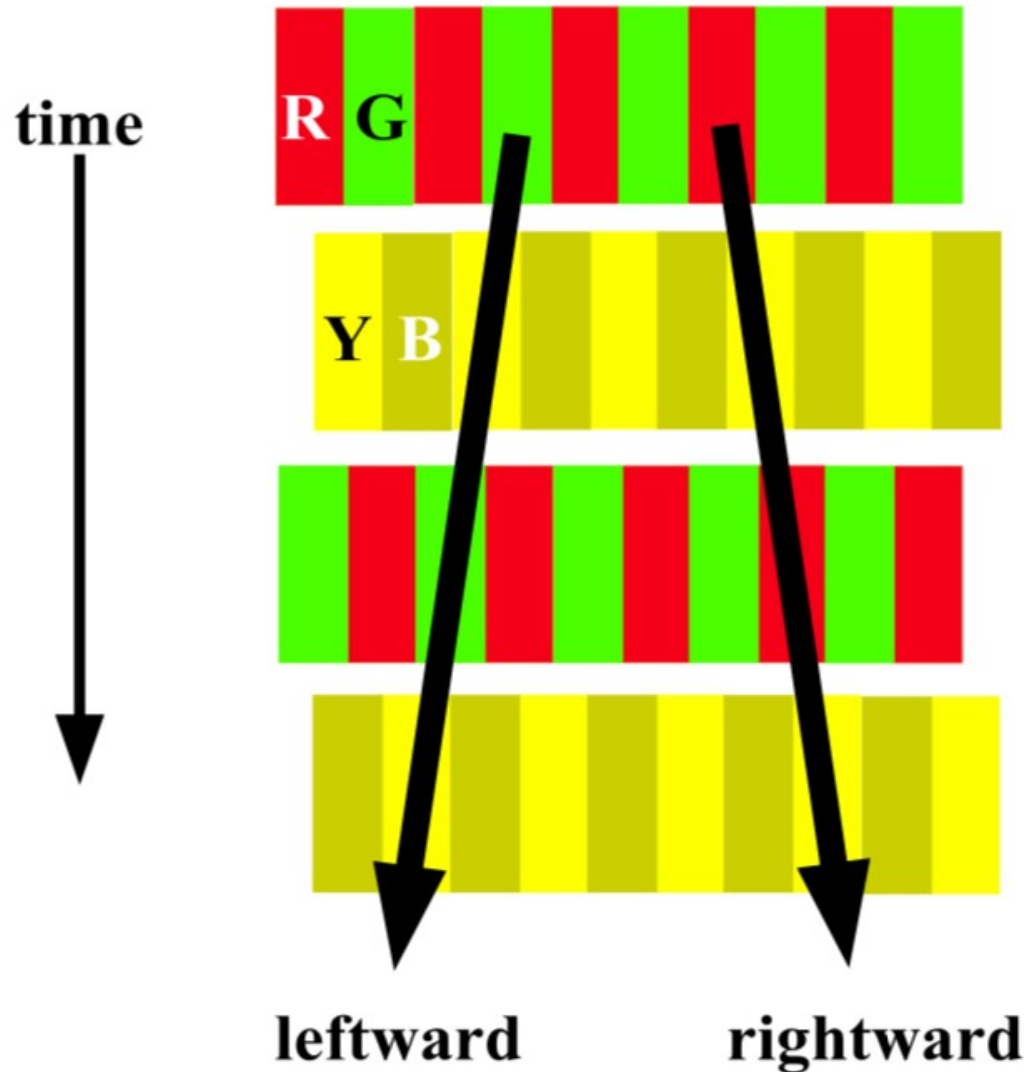
Back to gamma correction...

Perform 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)

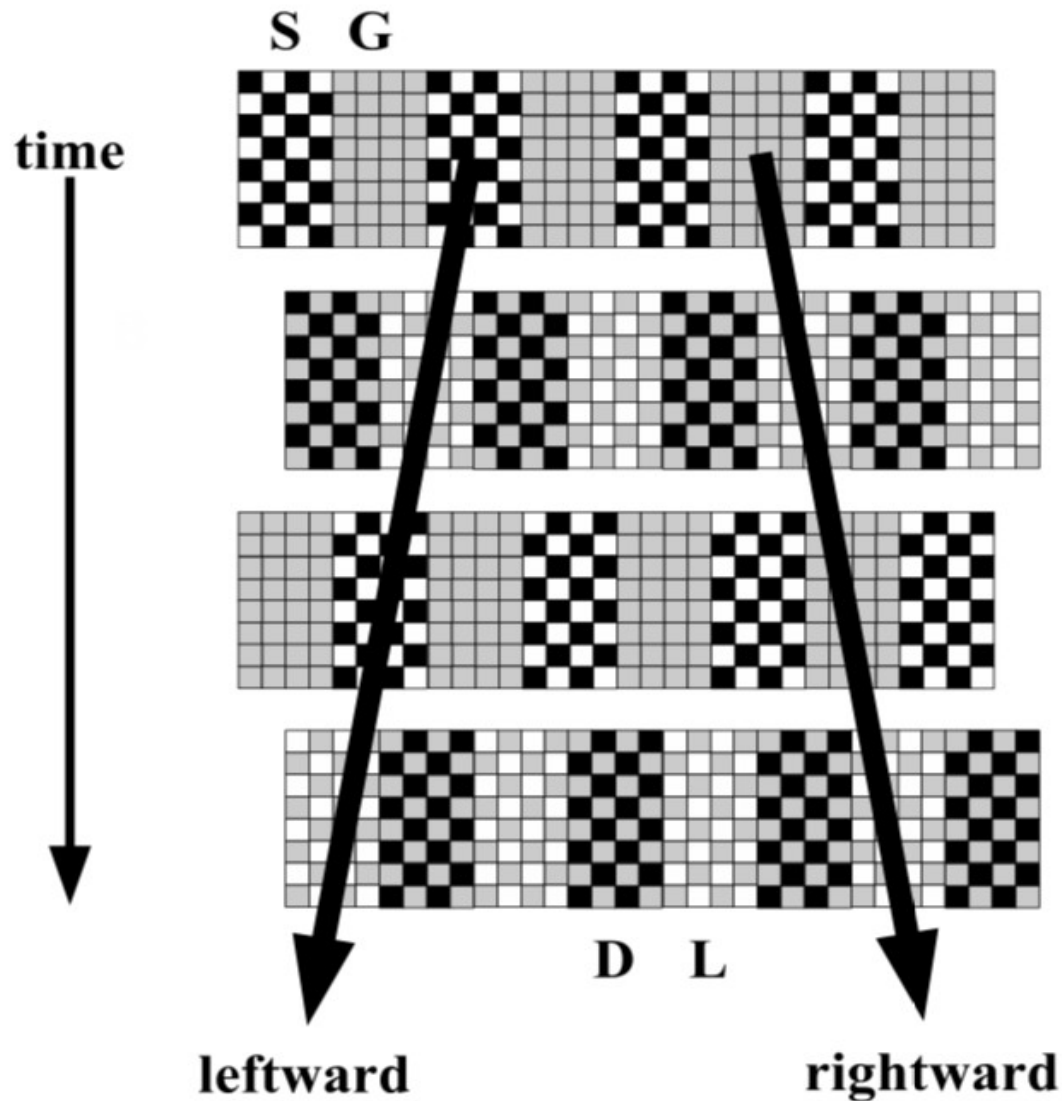


Figure from Mulligan (2009)

A curious, unexplained result

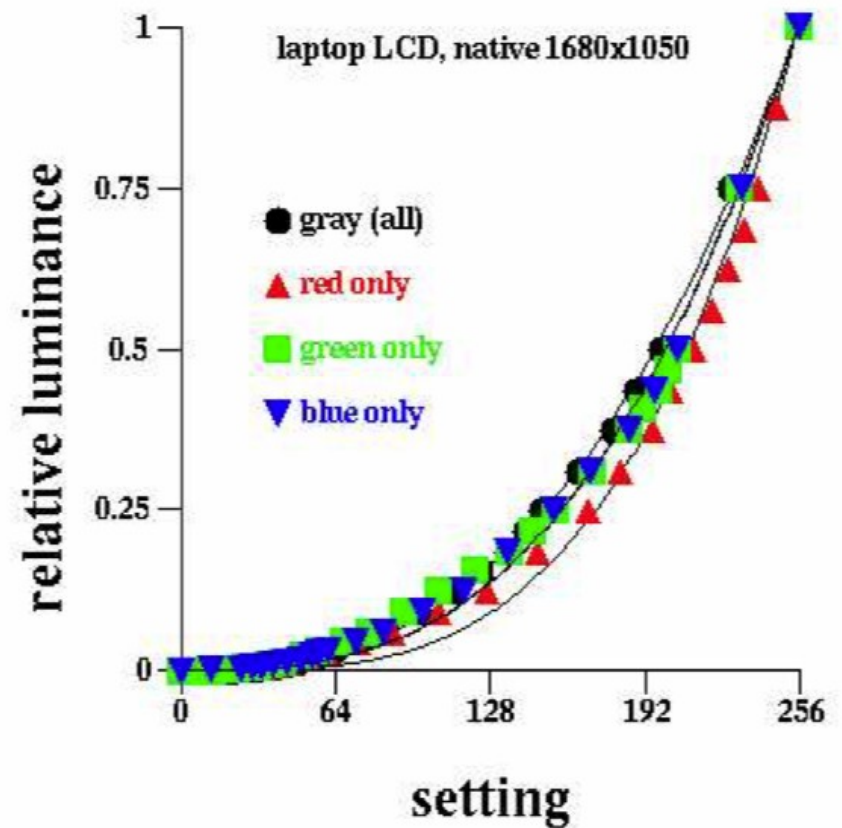
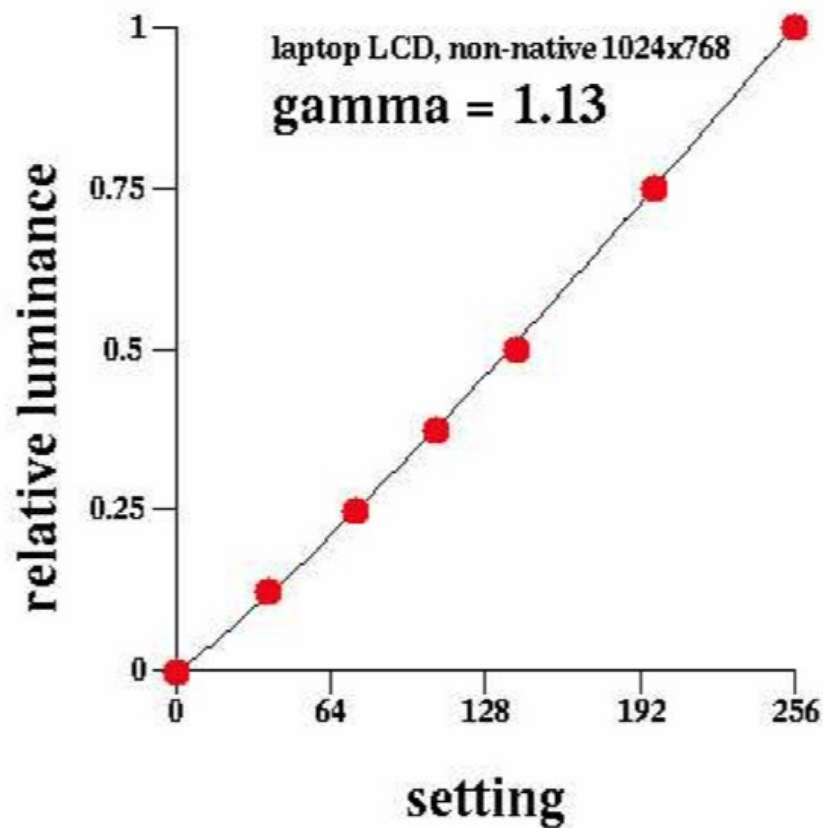


Figure from Mulligan (2009)

Another hardware oddity: iPod hysteresis

(measured with a photometer)

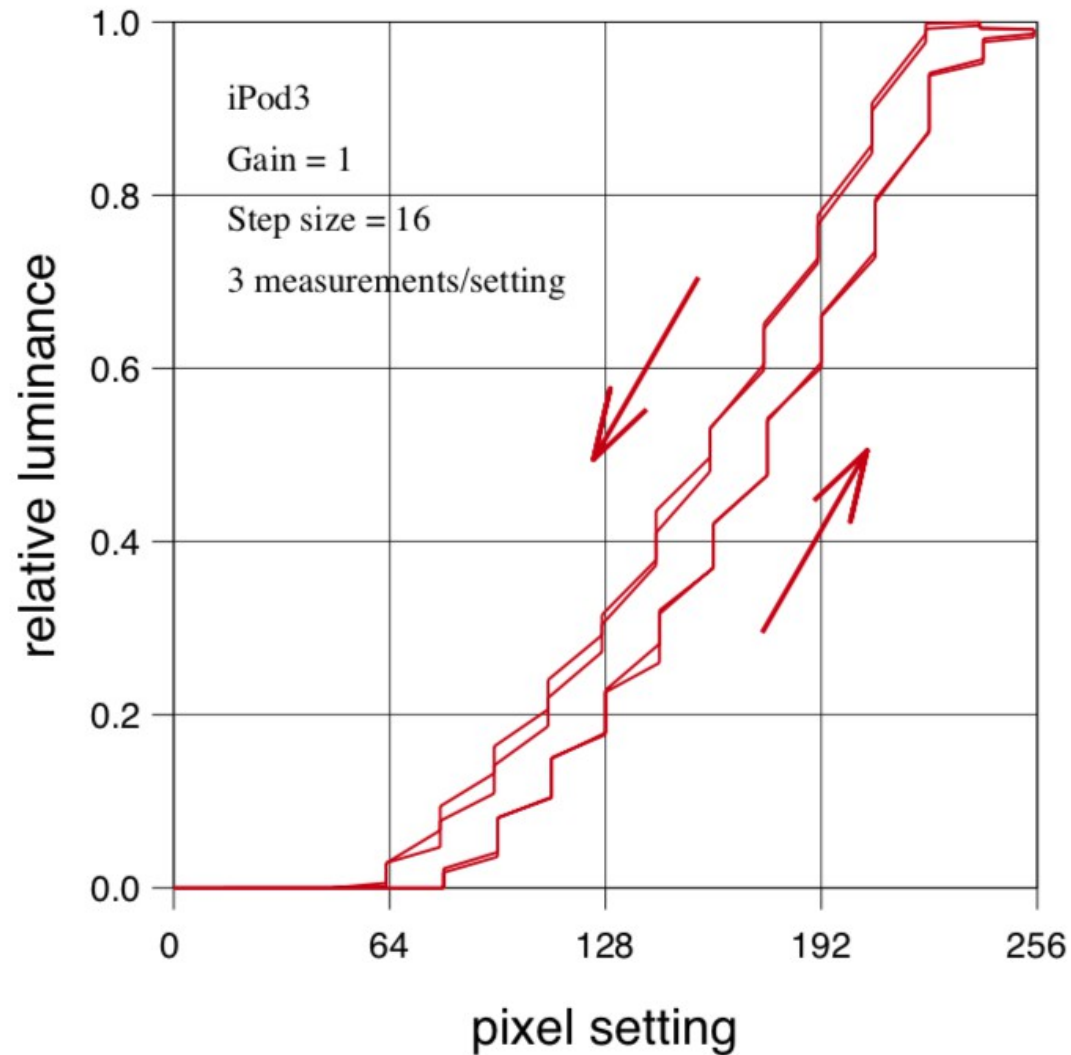


Figure from Mulligan (2015)

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

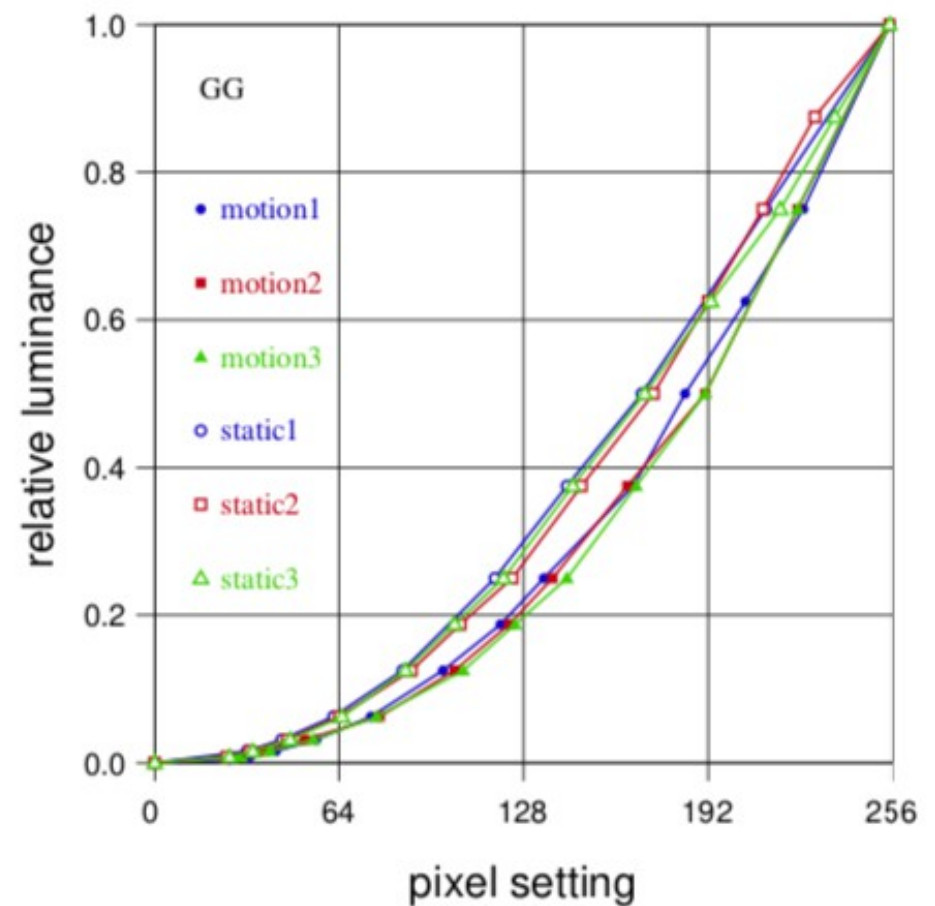
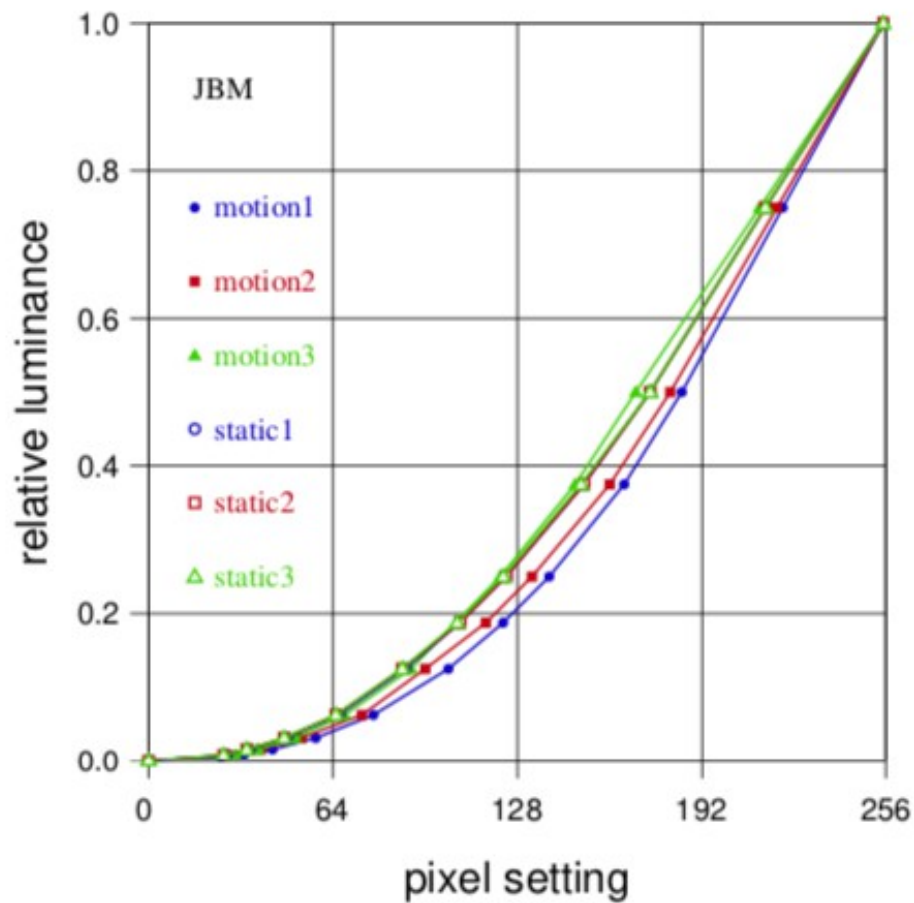


Figure from Mulligan (2016)

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

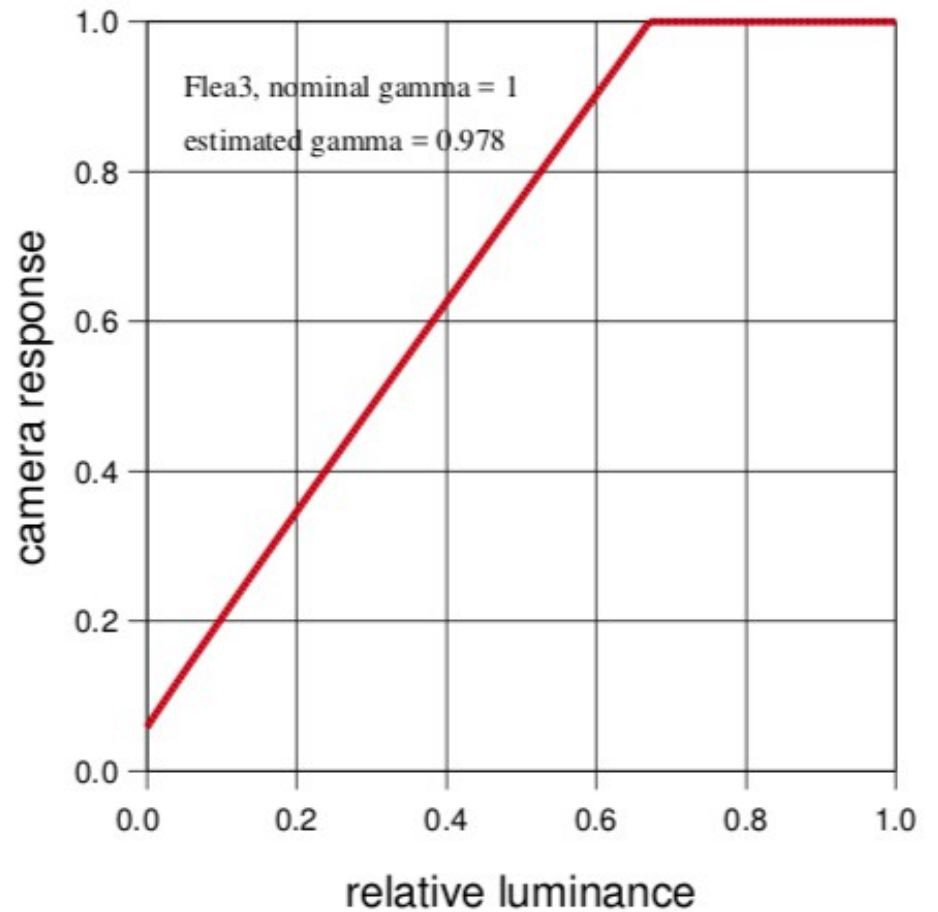
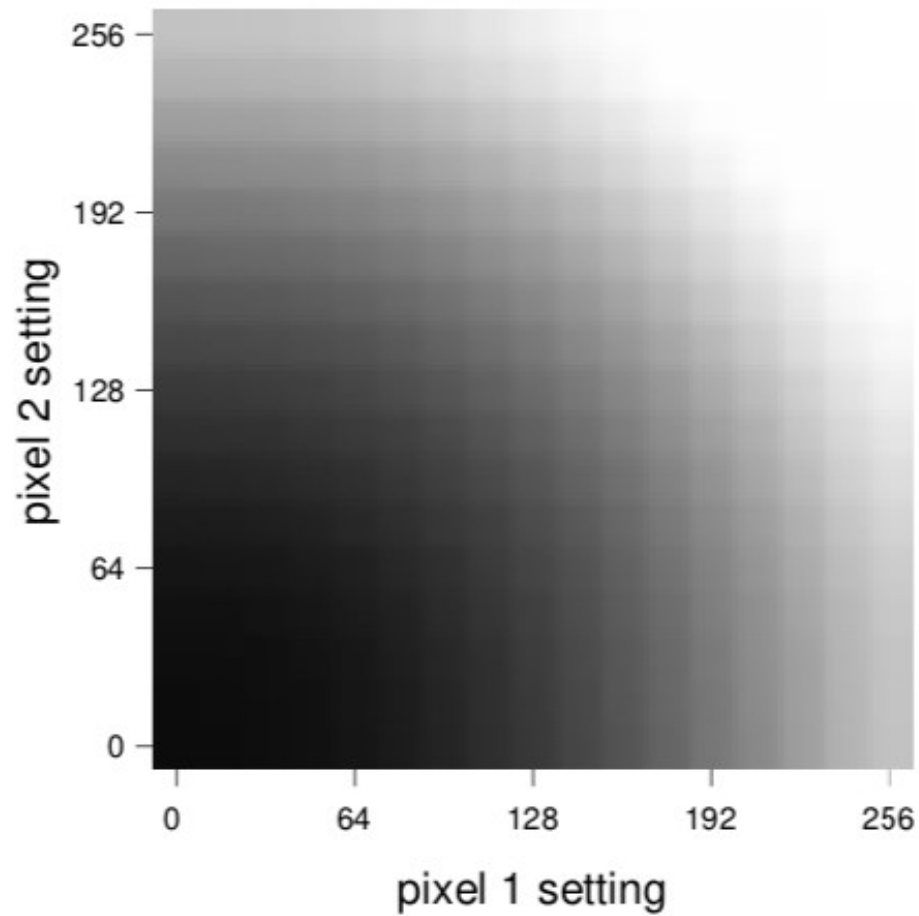


Figure from Mulligan (2016)

Camera vs. psychophysics

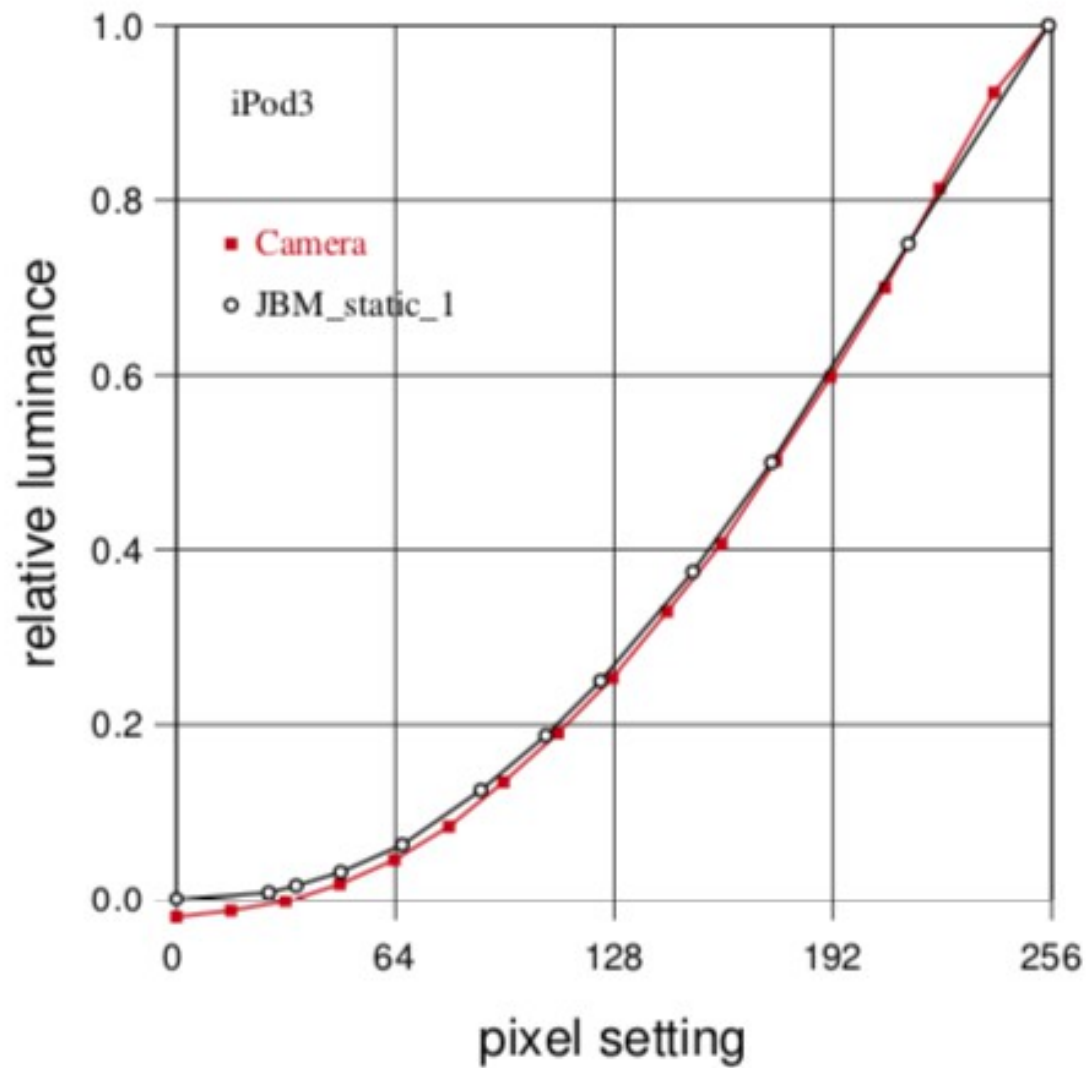


Figure from Mulligan (2016)

What about color?



Image from Mulligan (2009)

For more information:

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

Thanks for your attention!