Demosaicing and White Balancing

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Borrowed from Frédo Durand's Lectures at MIT

CCD color sampling

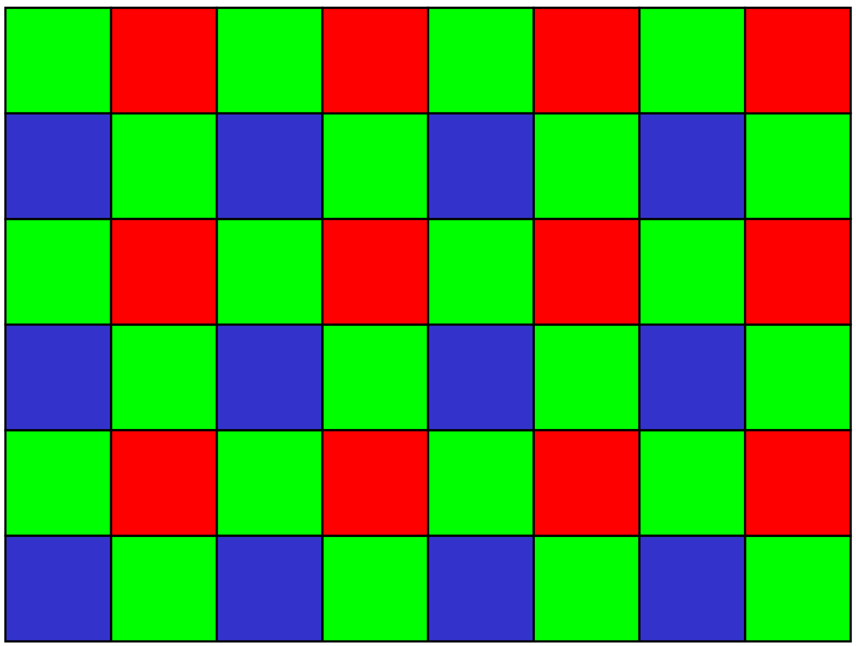
- Problem: a photosite can record only one number
- We need 3 numbers for color

Some approaches to color sensing

- Scan 3 times (temporal multiplexing)
  - Drum scanners
  - Flat-bed scanners
  - Russian photographs from 1800’s
- Use 3 detectors
  - High-end 3-tube or 3-ccd video cameras
- Use spatially offset color samples (spatial multiplexing)
  - Single-chip CCD color cameras
  - Human eye
- Multiplex in the depth of the sensor
  - Foveon

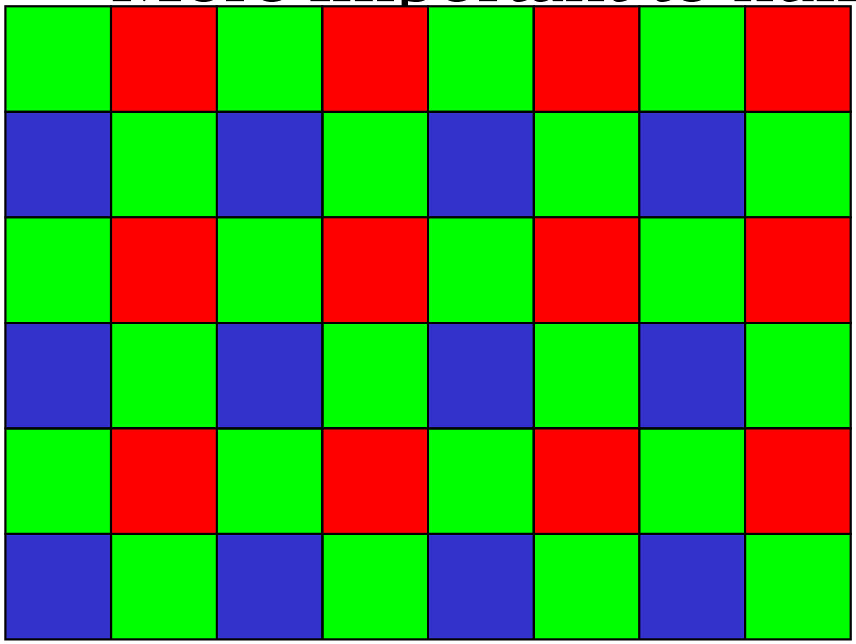
Bayer RGB mosaic

- Each photosite has a different color filter



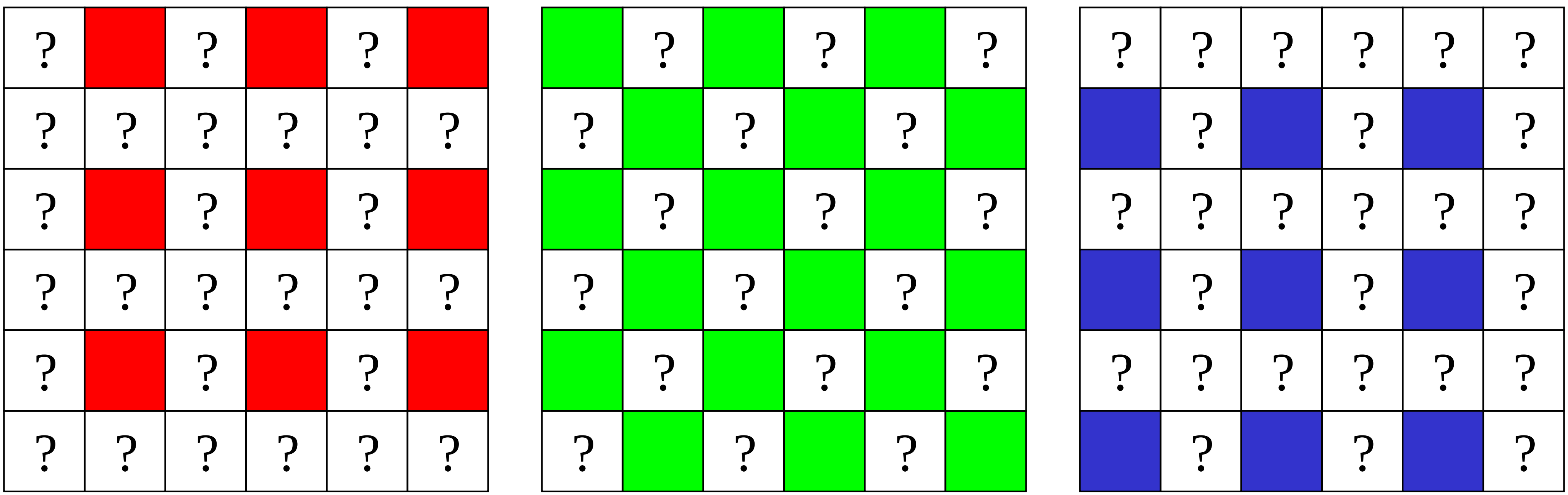
Bayer RGB mosaic

- Why more green?
  - We have 3 channels and square lattice don't like odd numbers
  - It's the spectrum "in the middle"
  - More important to human perception of luminance



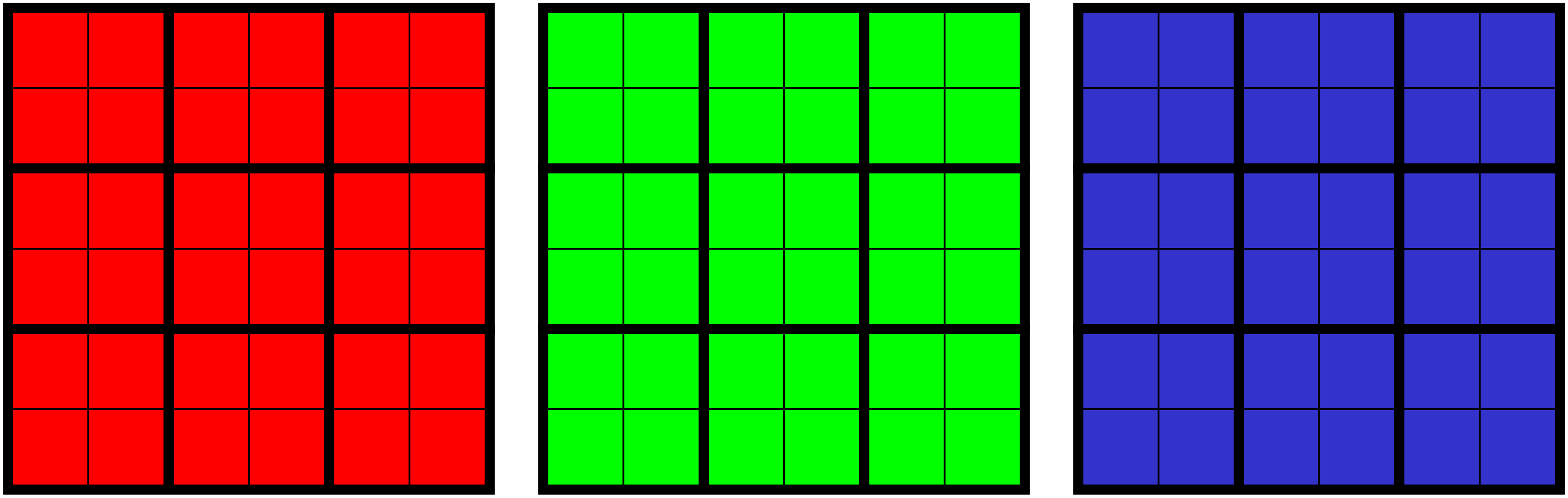
Demosaicing

- Interpolate missing values



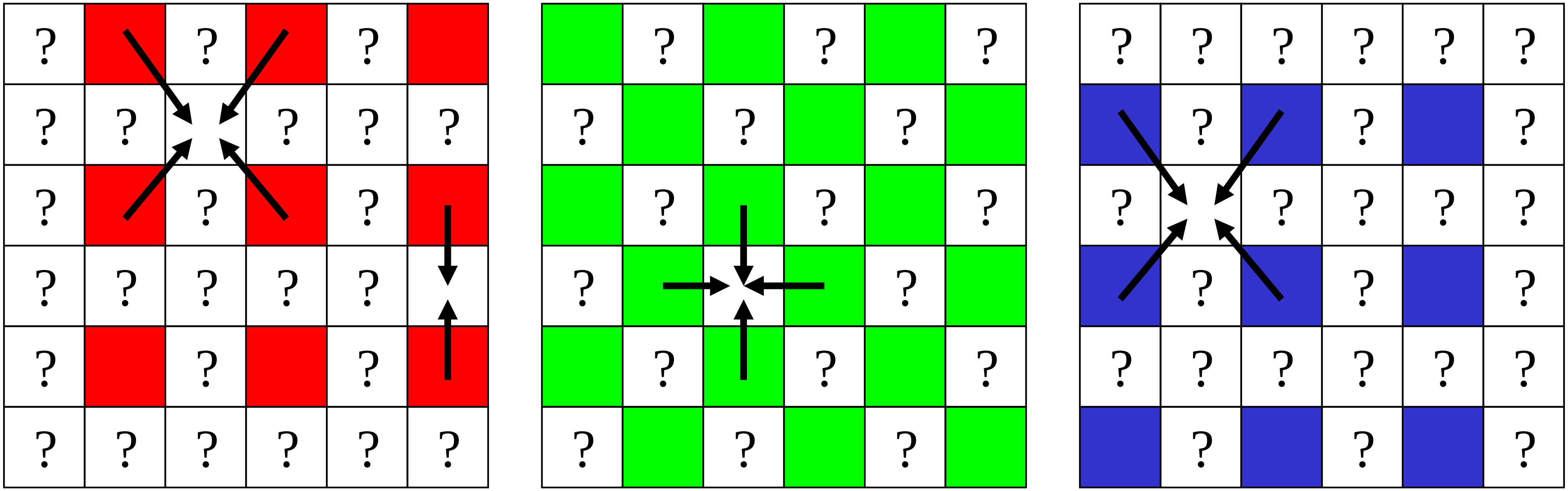
Demosaicing

- Simplest solution: downsample!
  - Nearest-neighbor reconstruction
- Problem: resolution loss (and megapixels are so important for marketing!)



Linear interpolation

- Average of the 4 or 2 nearest neighbors
  - Linear (tent) kernel
- Smoother kernels can also be used (e.g. bicubic) but need wider support



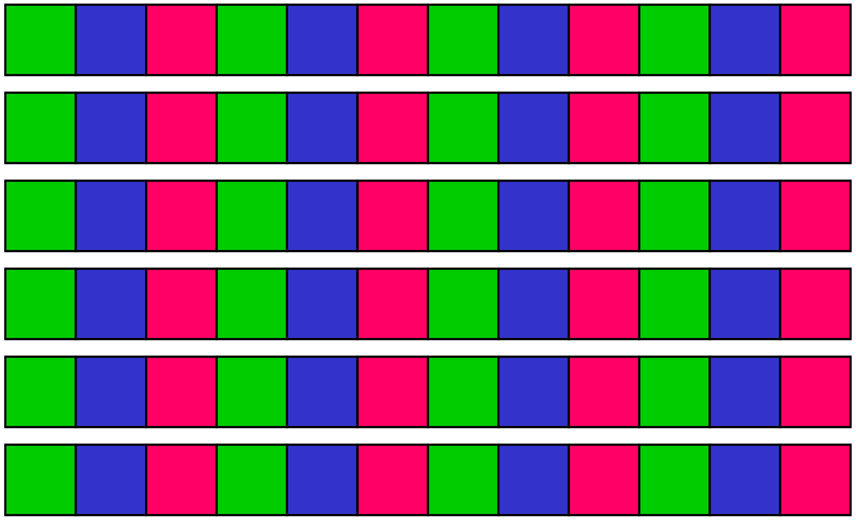
Typical errors in spatial multiplexing approach.

- Color fringes.

CCD color filter pattern

detector

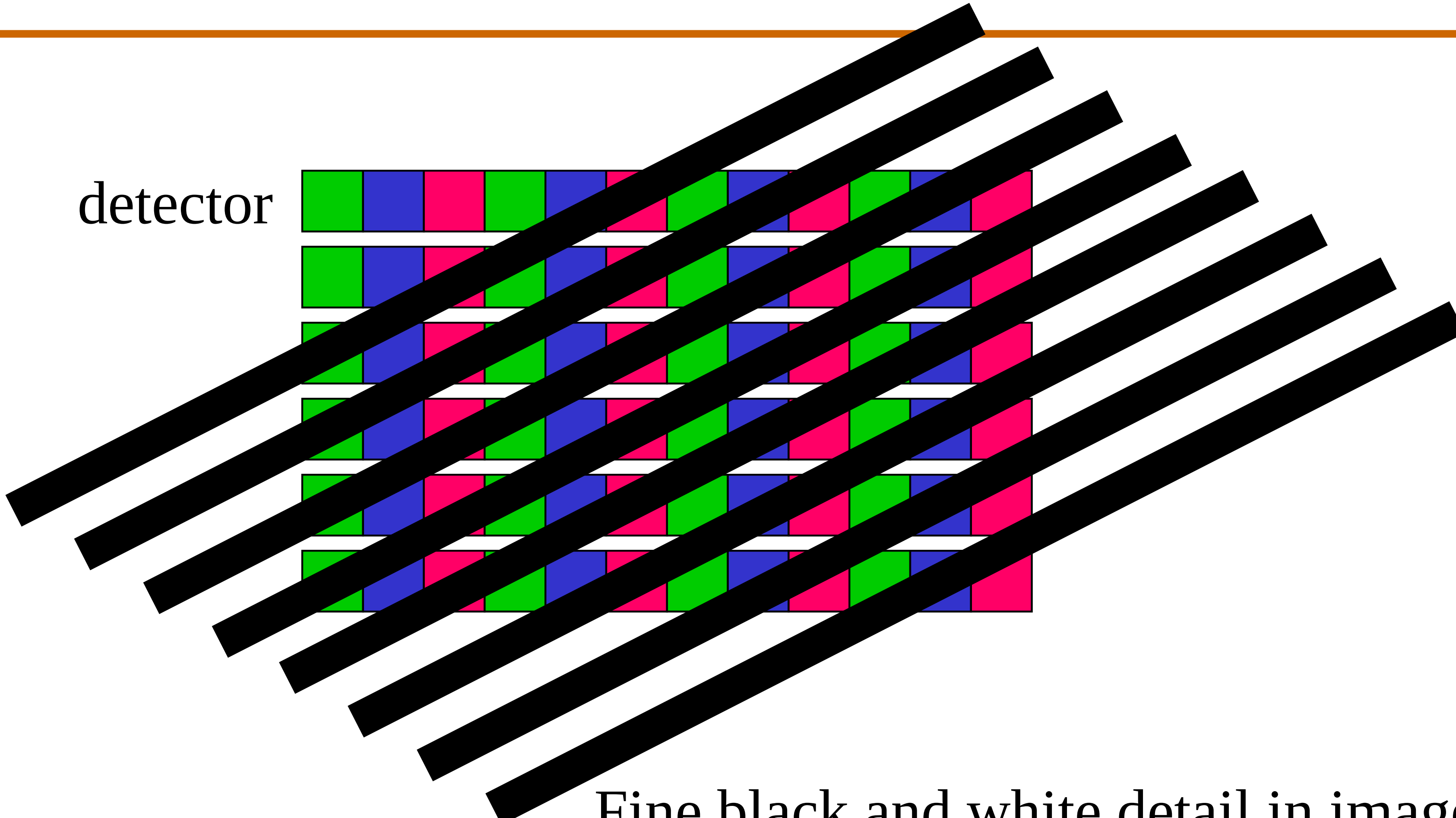
(simplified for simpler visualization)



Typical color moire patterns

Blow-up of electronic camera image. Notice spurious colors in the regions of fine detail in the plants.

The cause of color moire

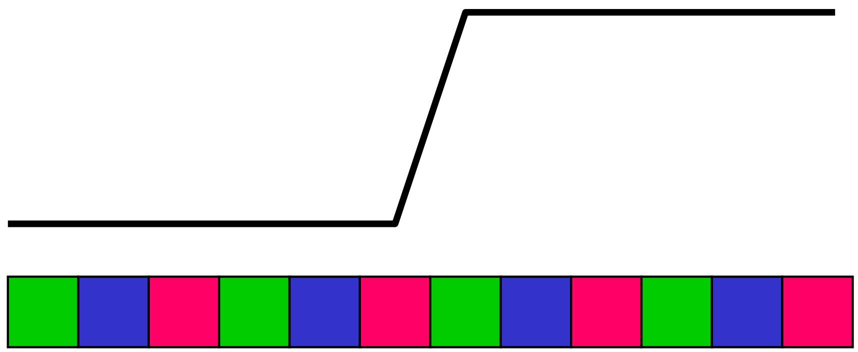


Fine black and white detail in image mis-interpreted as color information.

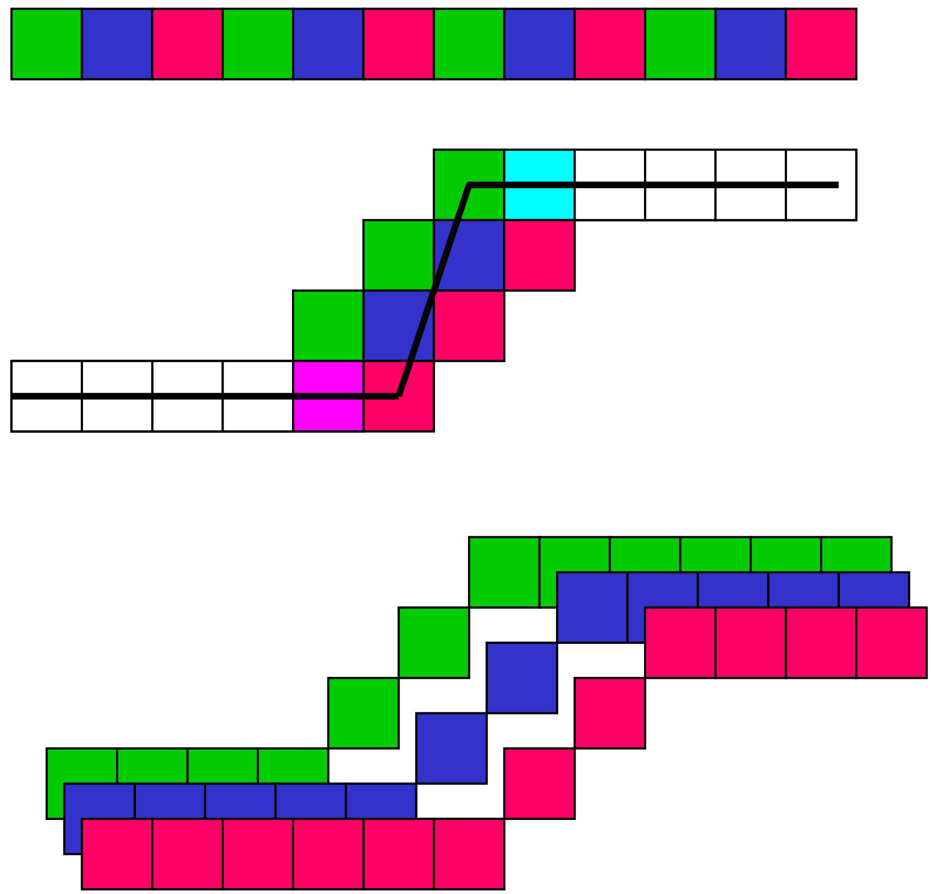
Black and white edge falling on color CCD detector

Black and white image (edge)

Detector pixel colors



Color sampling artifact



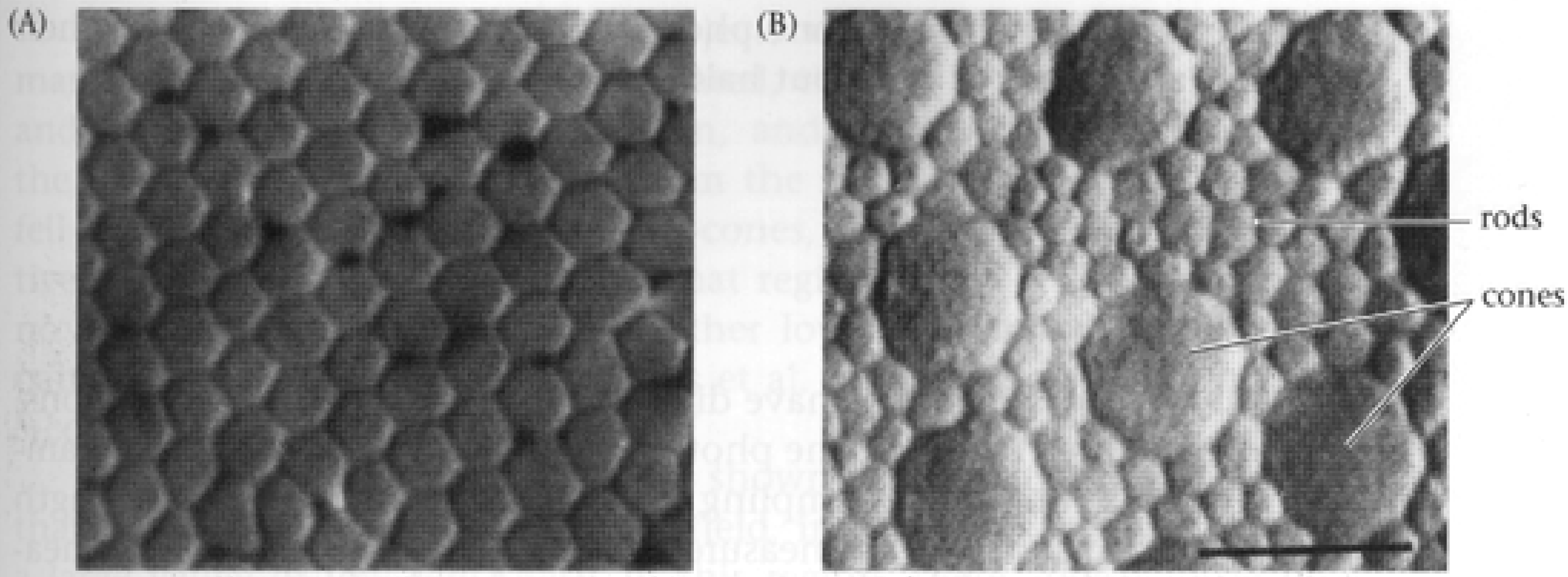
Interpolated pixel colors,
for grey edge falling on colored
detectors (linear interpolation).

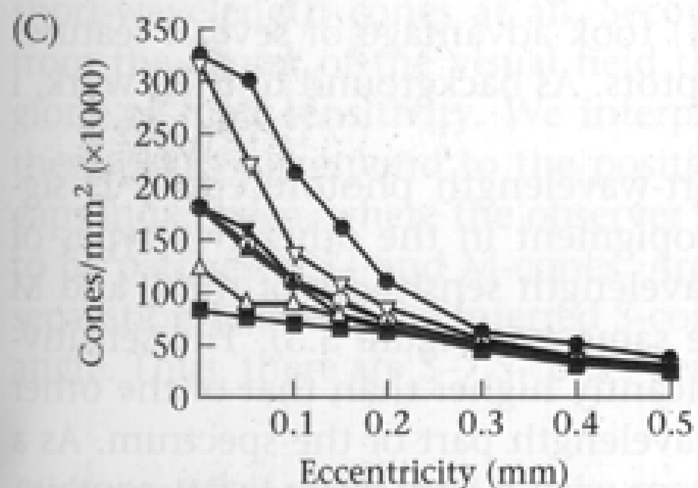
Color sampling artifacts

Question

Have any of you seen color sampling artifacts from the spatially offset color sampling in your camera?

Human Photoreceptors





3.4 THE SPATIAL MOSAIC OF THE HUMAN CONES. Cross sections of the human retina at the level of the inner segments showing (A) cones in the fovea, and (B) cones in the periphery. Note the size difference (scale bar = 10 μm), and that, as the separation between cones grows, the rod receptors fill in the spaces. (C) Cone density plotted as a function of distance from the center of the fovea for seven human retinas; cone density decreases with distance from the fovea. Source: Curcio et al., 1990.

(From Foundations of Vision, by Brian Wandell, Sinauer Assoc.)

Human Photoreceptors

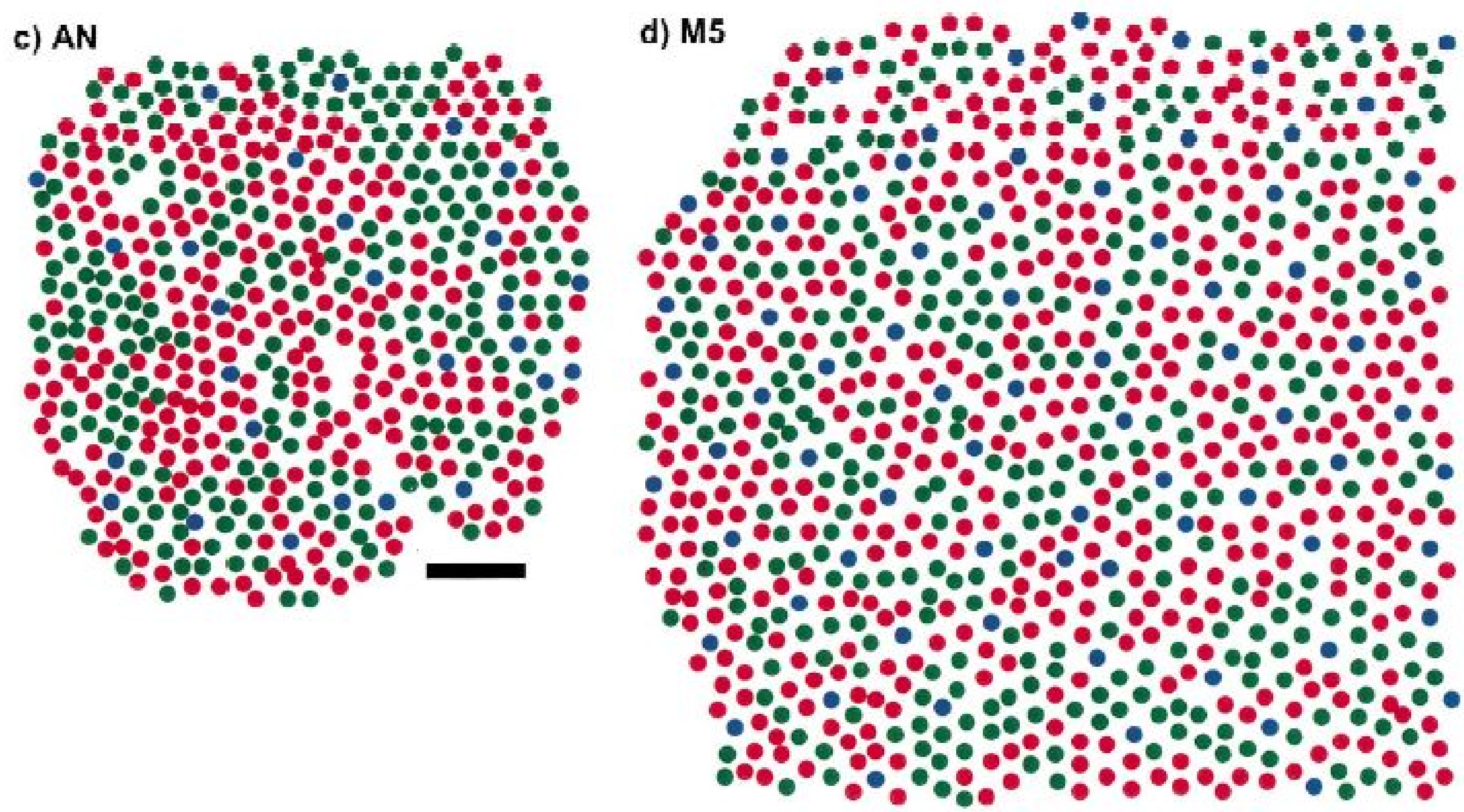


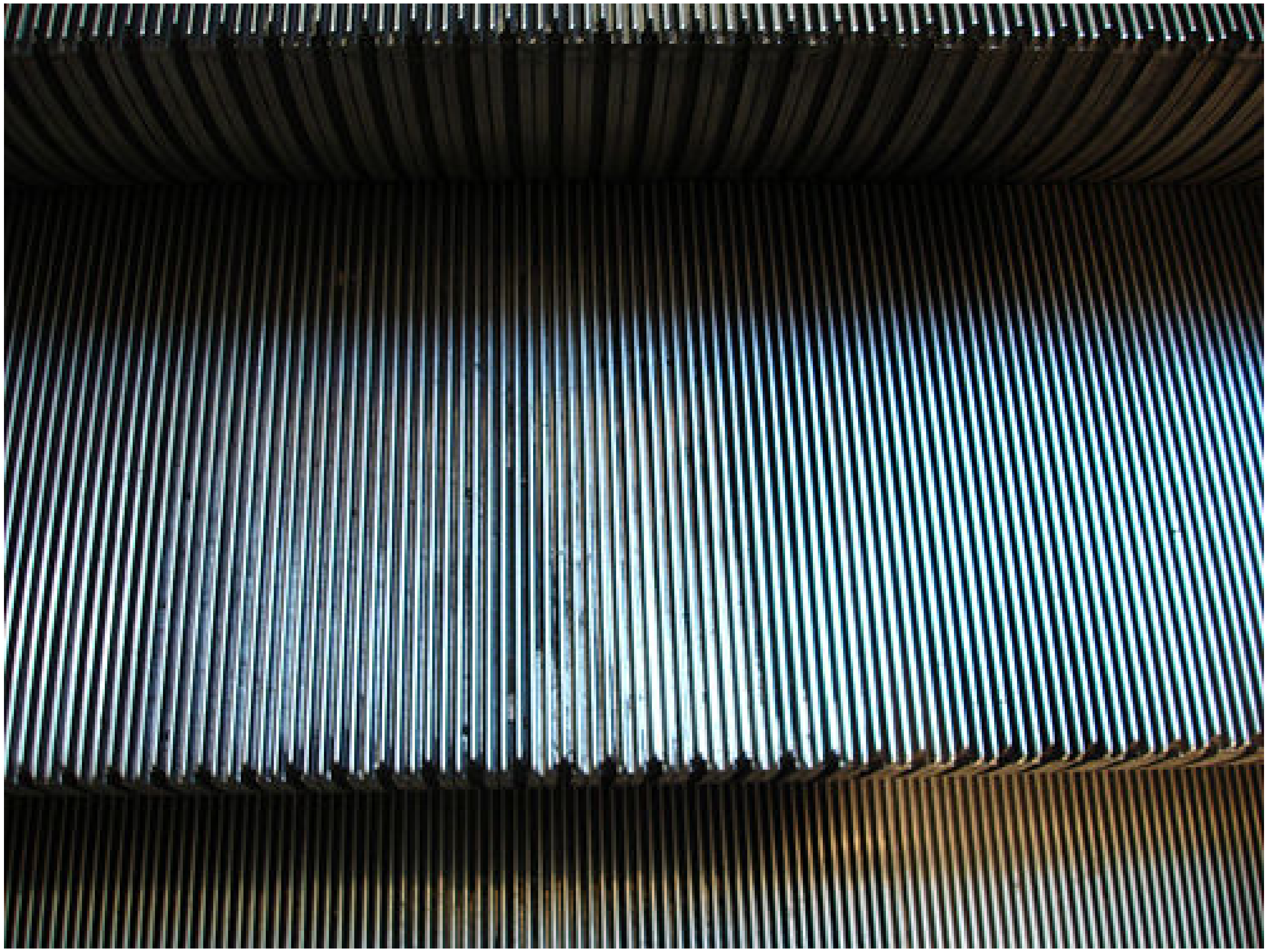
Fig. 2. L, M and S cone mosaics for two humans: JW (a nasal and a temporal location is shown, labeled JWN and JWT, respectively); and AN, and one macaque, M5. L, M and S cones are shown as red, green and blue dots respectively. For JWN, a patch of central cones was not identified due to a capillary that obscured those cones. All mosaics are shown to the same scale. Scale bar = 5 μm.

http://www.cns.nyu.edu/~pl/pubs/Roorda_et_al01.pdf

Question

Have any of you seen color sampling artifacts from the spatially offset color sampling in your own visual systems?

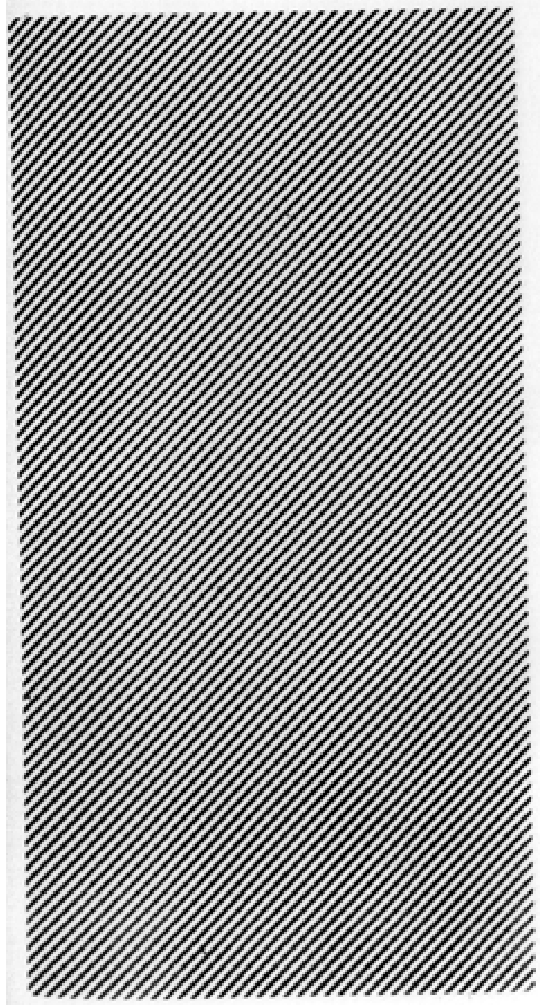
Where I've seen color fringe reconstruction artifacts in my ordinary world



http://static.flickr.com/21/31393422_23013da003.jpg

Brewster's colors—evidence of interpolation from spatially offset color samples

Scale relative to human photoreceptor size: each line covers about 7 photoreceptors.



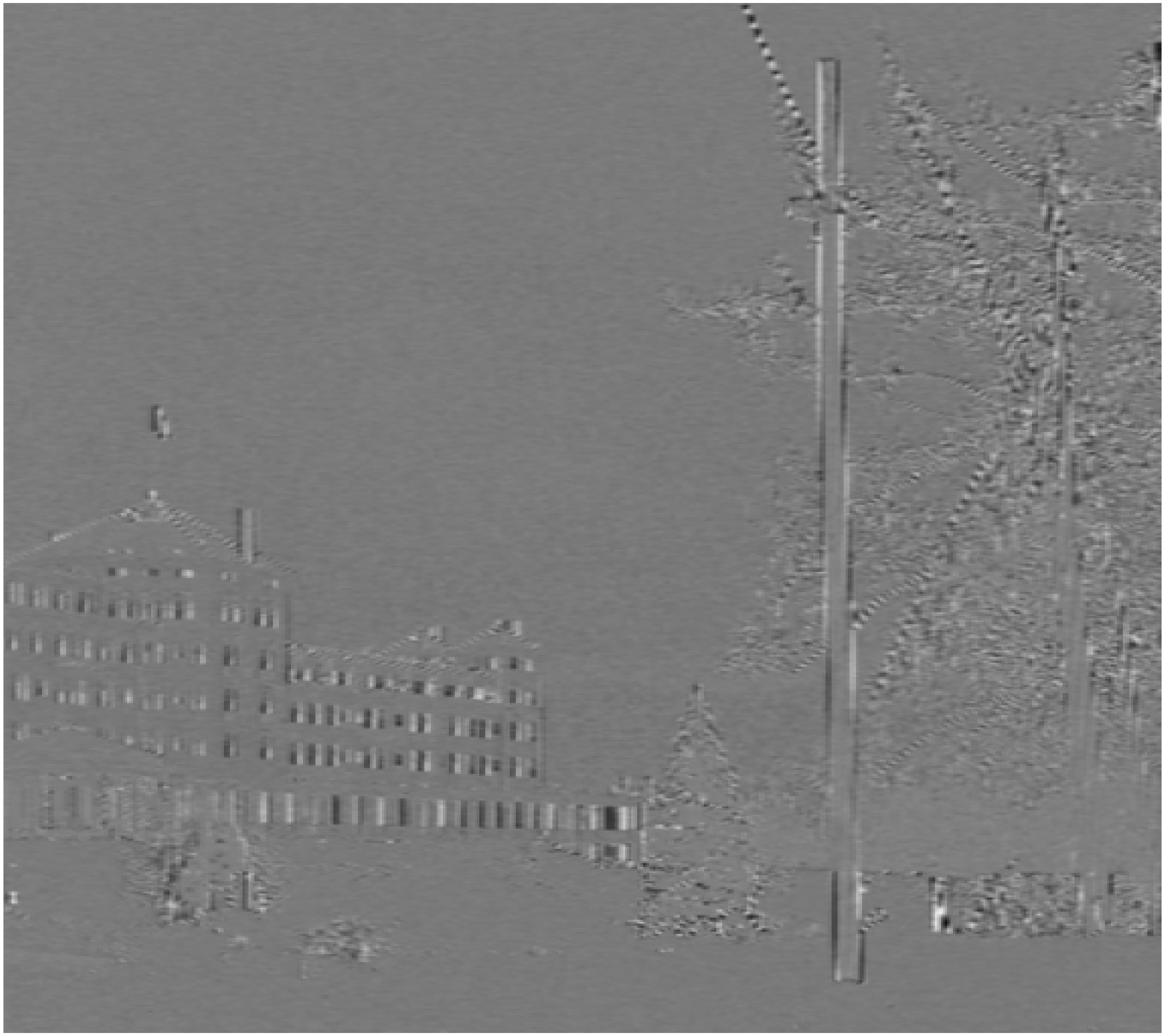
8 STATIONARY BLACK-AND-WHITE PATTERN in which pastel-like hues are seen as the eyes move slowly over the pattern.

from: Color Vision, by Leo M. Hurvich
Sinauer Assoc.

Motivation for median filter interpolation

The color fringe artifacts are obvious; we can point to them. Goal: can we characterize the color fringe artifacts mathematically? Perhaps that would lead to a way to remove them…

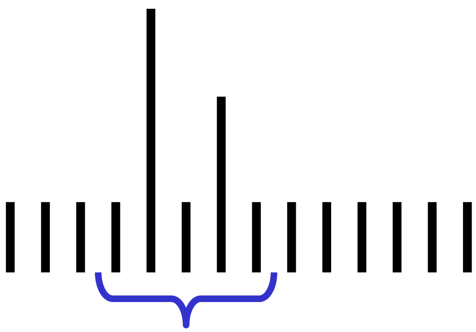
R-G, after linear interpolation



Median filter

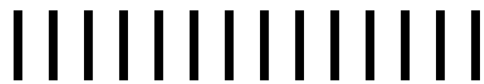
Replace each pixel by the median over N pixels (5 pixels, for these examples). Generalizes to “rank order” filters.

In:



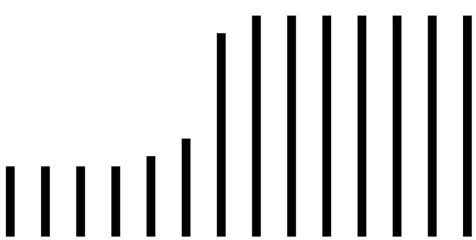
5-pixel neighborhood

Out:

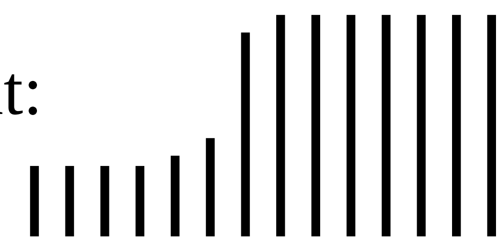


Spike noise is removed

In:

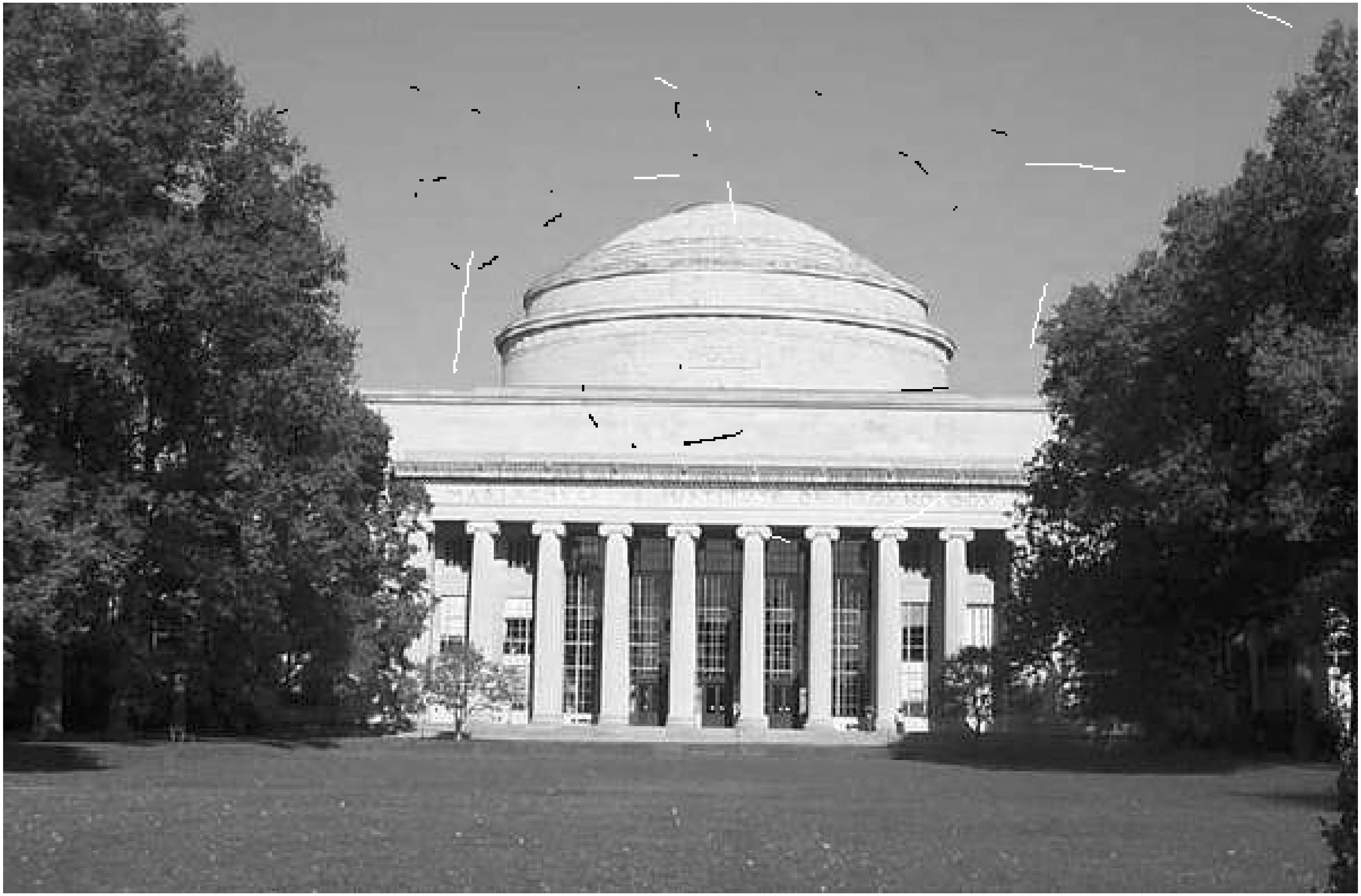


Out:



Monotonic edges remain unchanged

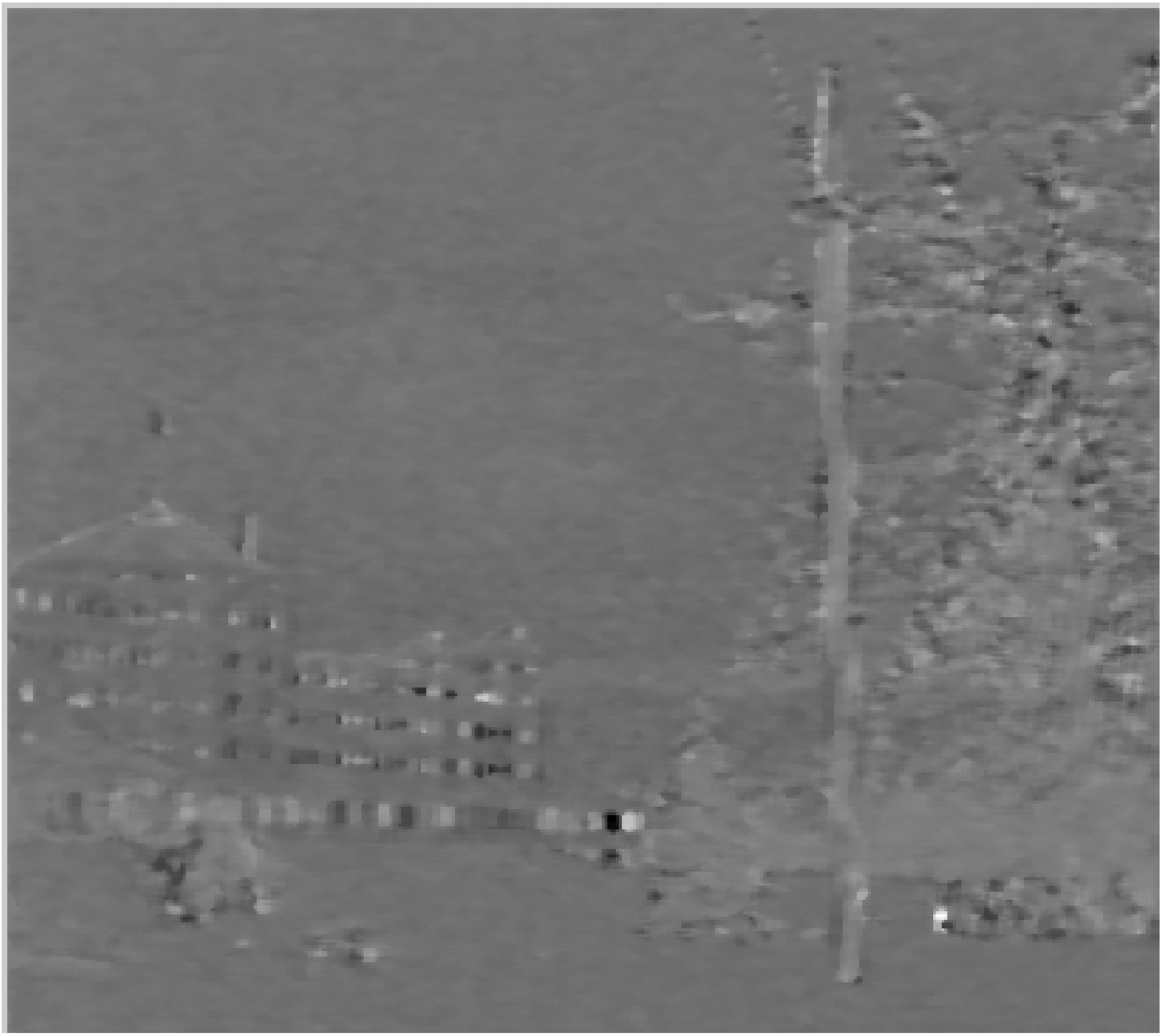
Degraded image



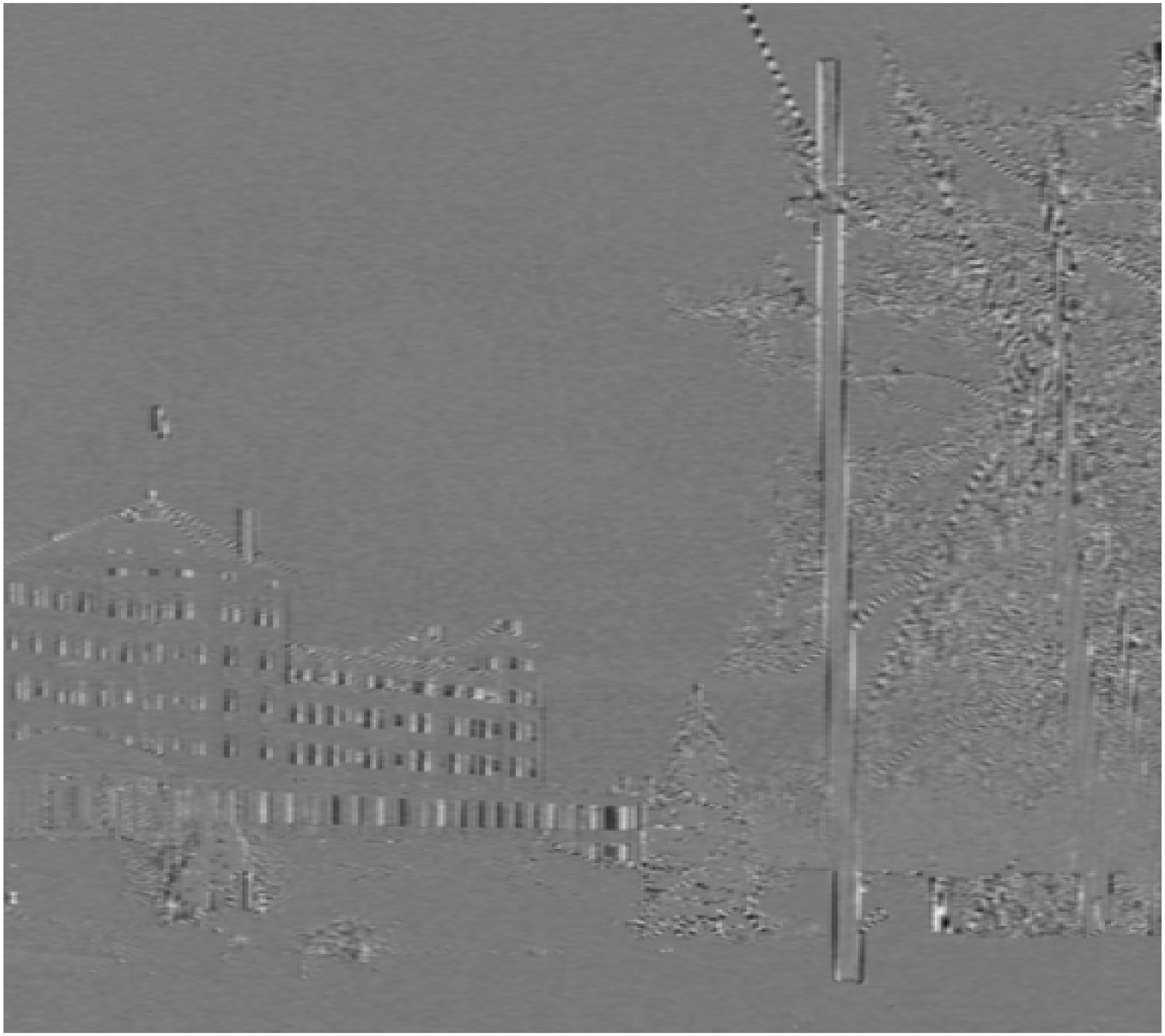
Radius 1 median filter

Radius 2 median filter

R – G, median filtered (5x5)



R – G



Median Filter Interpolation

- Perform first interpolation on isolated color channels.
- Compute color difference signals.
- Median filter the color difference signal.
- Reconstruct the 3-color image.

Recombining the median filtered colors

Linear interpolation

Median filter interpolation

Beyond linear interpolation between samples of the same color

- Luminance highs
- Median filter interpolation
- Regression
- Gaussian method
- Regression, including non-linear terms
- Multiple linear regressors

Other possibilities

- CMY mosaic
  - Pro: gather more light per photosite
  - Con: not directly what we want, potential loss of color sensitivity

Foveon sensor

- Red gets absorbed preferably
- The deeper in the silicon, the bluer

- Pros: no demosaicing
- Cons: potentially more noise, lower resolution in practice

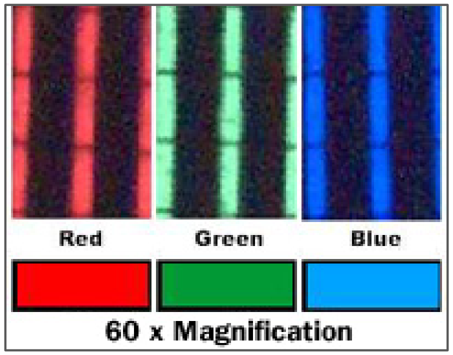
Extension

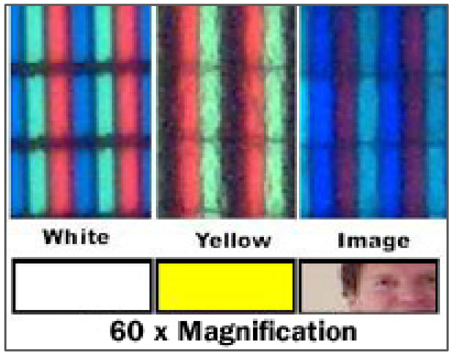
- Mosaicing can be used to gather more information
  - Use neutral density filters to get more dynamic range
  - Polarizers
  - Etc.
- Shree Nayar’s work, Fuji’s super CCD

Questions?

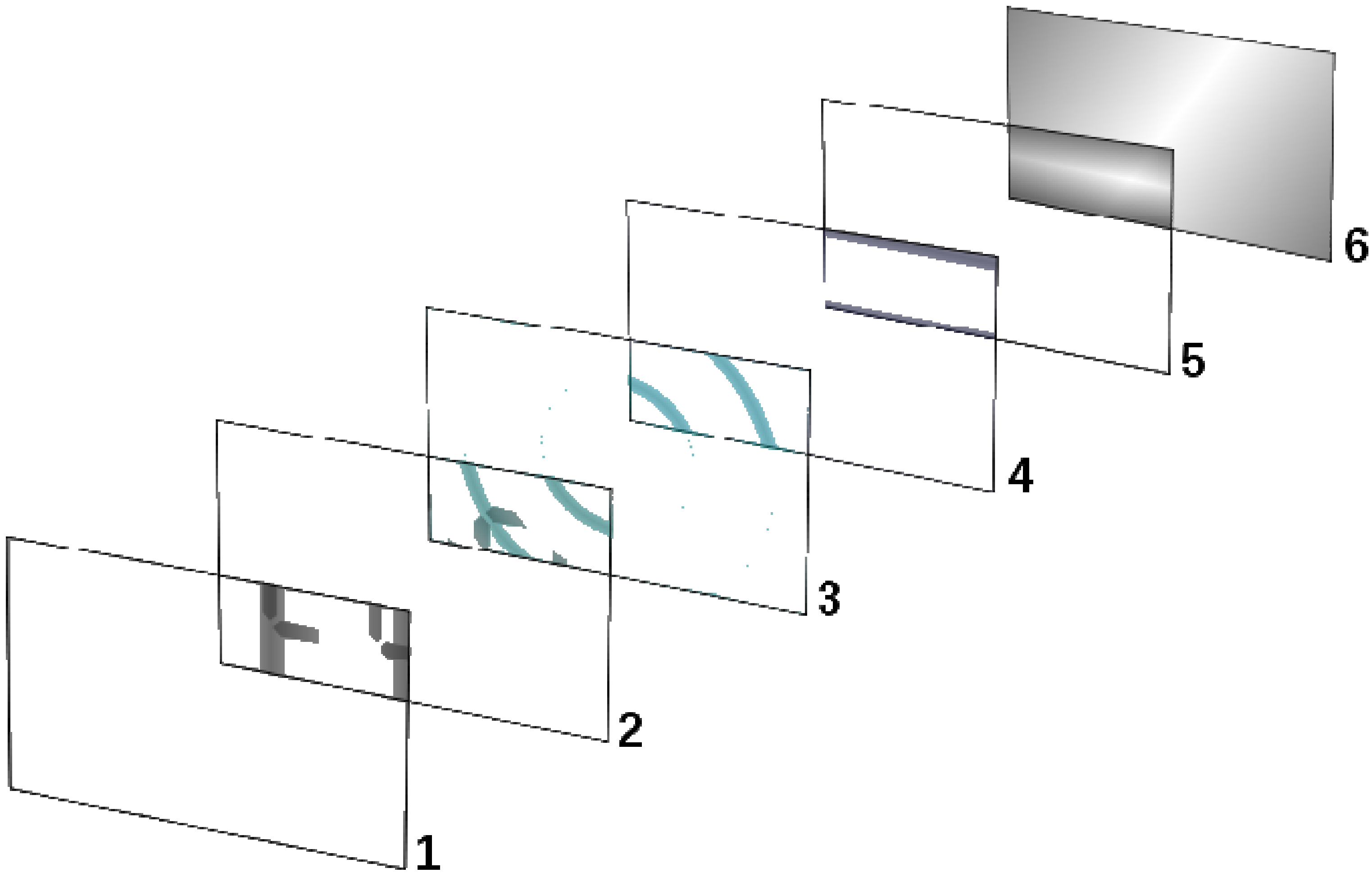
Where else CFAs are being used?

- LCD Panels





How LCD panels work!



Questions?

White balance & Chromatic adaptation

- Different illuminants have different color temperature
- Our eyes adapt to this: Chromatic adaptation
  - We actually adapt better in brighter scenes
  - This is why candlelit scenes still look yellow

White balance problem

- When watching a picture on screen or print, we adapt to the illuminant of the room, not that of the scene in the picture
- The eye cares more about objects’ intrinsic color, not the color of the light leaving the objects
- We need to discount the color of the light source

White balance & Film

- Different types of film for fluorescent, tungsten, daylight
- Need to change film!

- Electronic & Digital imaging are more flexible

Von Kries adaptation

- Multiply each channel by a gain factor
- Note that the light source could have a more complex effect
  - Arbitrary 3x3 matrix
  - More complex spetrum transformation

Best way to do white balance

- Grey card
  - Take a picture of a neutral object (white or gray)
  - Deduce the weight of each channel
  - If the object is recoded as r_w, g_w, b_w use weights $1/r_w$, $1/g_w$, $1/b_w$

Without grey cards

- We need to “guess” which pixels correspond to white objects

Grey world assumption

- The average color in the image is grey
- Use weights

$$\frac{1}{\int_{image} r}, \frac{1}{\int_{image} g}, \frac{1}{\int_{image} b}$$

- Note that this also sets the exposure/brightness
- Usually assumes 18% grey

Brightest pixel assumption

- Highlights usually have the color of the light source
  - At least for dielectric materials
- Do white balance by using the brightest pixels
  - Plus potentially a bunch of heuristics
  - In particular use a pixel that is not saturated/clipped