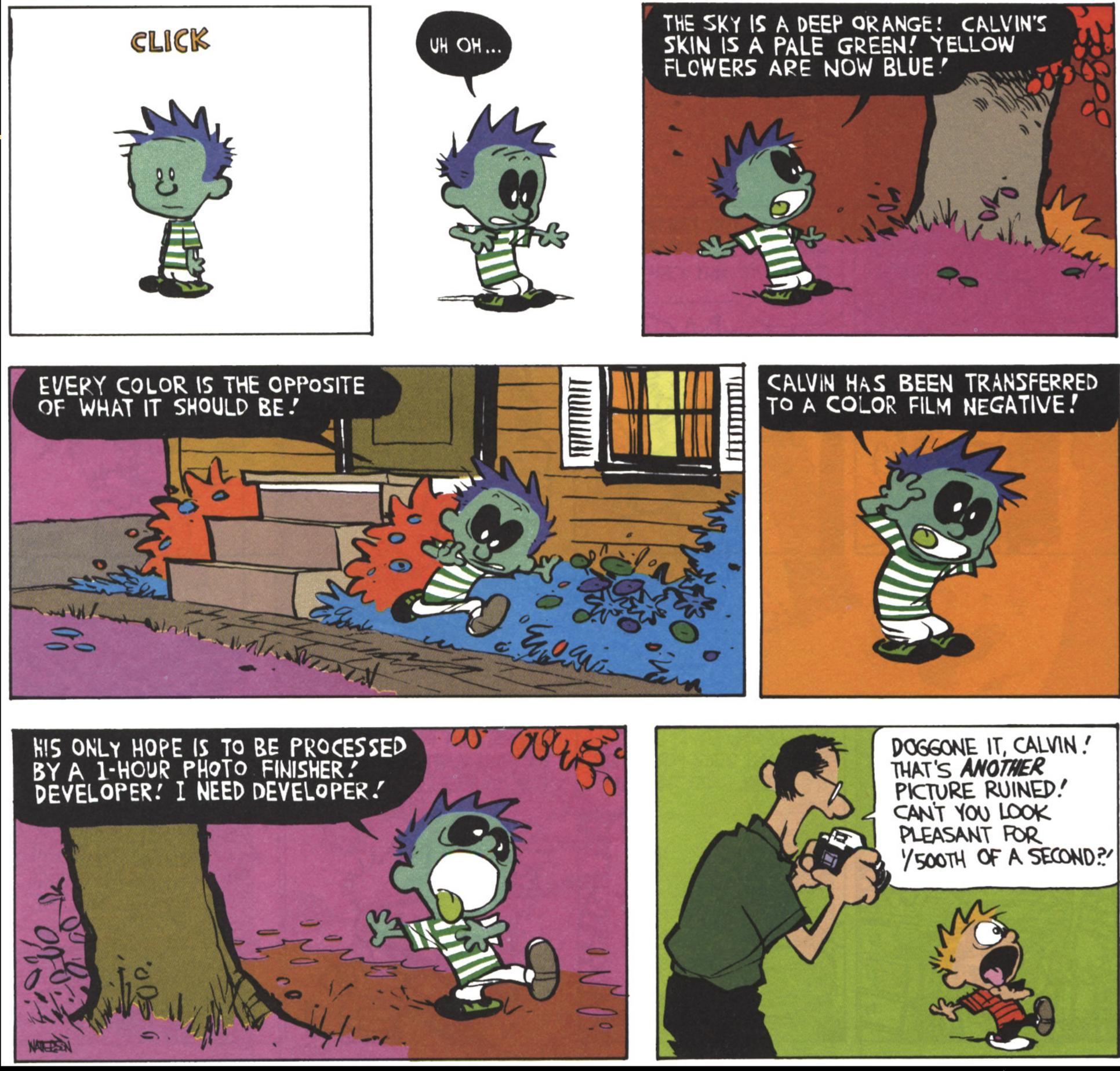
Questions?


CLICK
UH OH...
THE SKY IS A DEEP ORANGE! CALVIN'S SKIN IS A PALE GREEN! YELLOW FLOWERS ARE NOW BLUE!
EVERY COLOR IS THE OPPOSITE OF WHAT IT SHOULD BE!
CALVIN HAS BEEN TRANSFERRED TO A COLOR FILM NEGATIVE!
HIS ONLY HOPE IS TO BE PROCESSED BY A 1-HOUR PHOTO FINISHER! DEVELOPER! I NEED DEVELOPER!
DOGGONE IT, CALVIN! THAT'S ANOTHER PICTURE RUINED! CAN'T YOU LOOK PLEASANT FOR 1/500TH OF A SECOND?!
WATTERSON

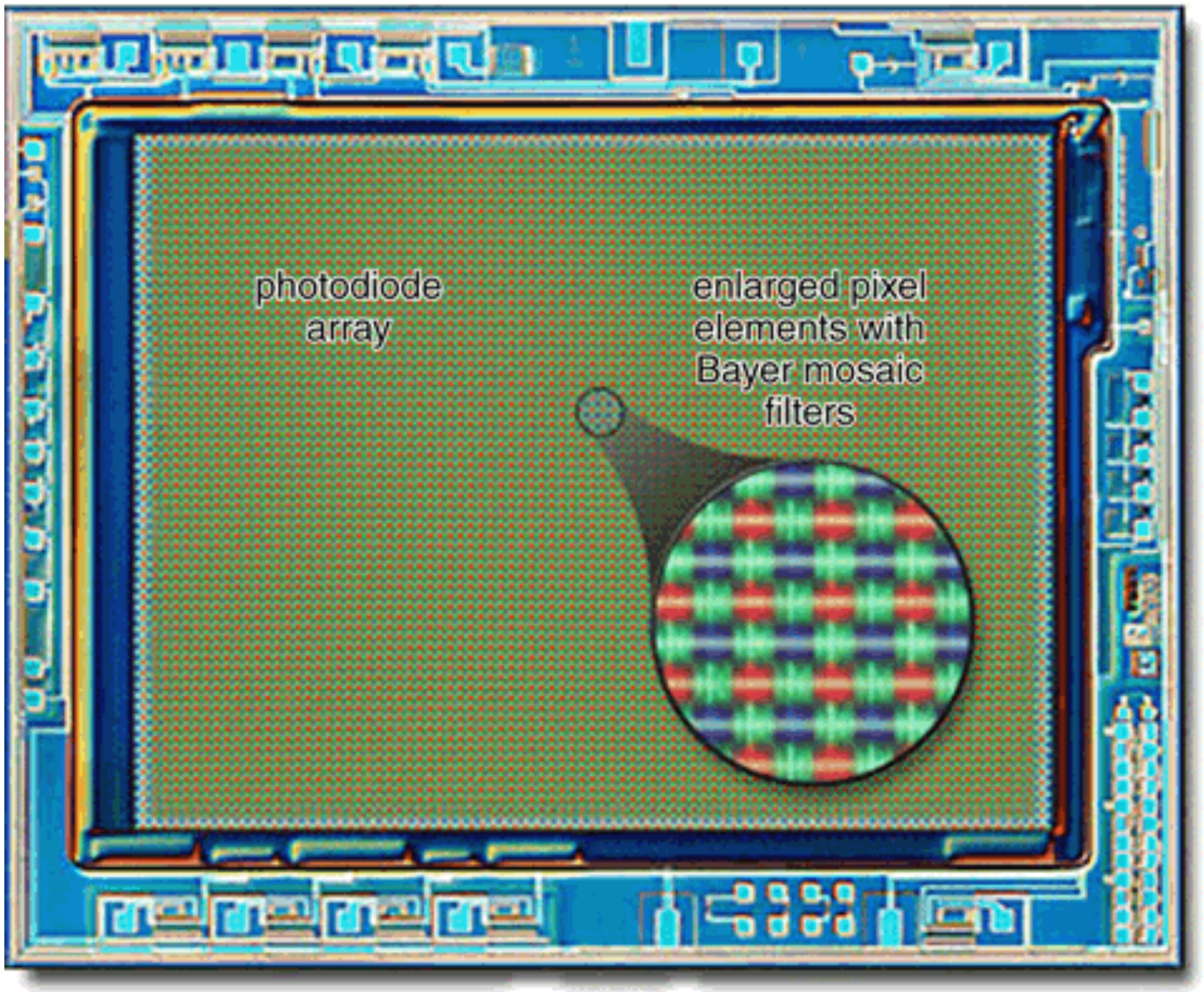
Demosaicking



Fredo Durand
MIT EECS 6.8370/1

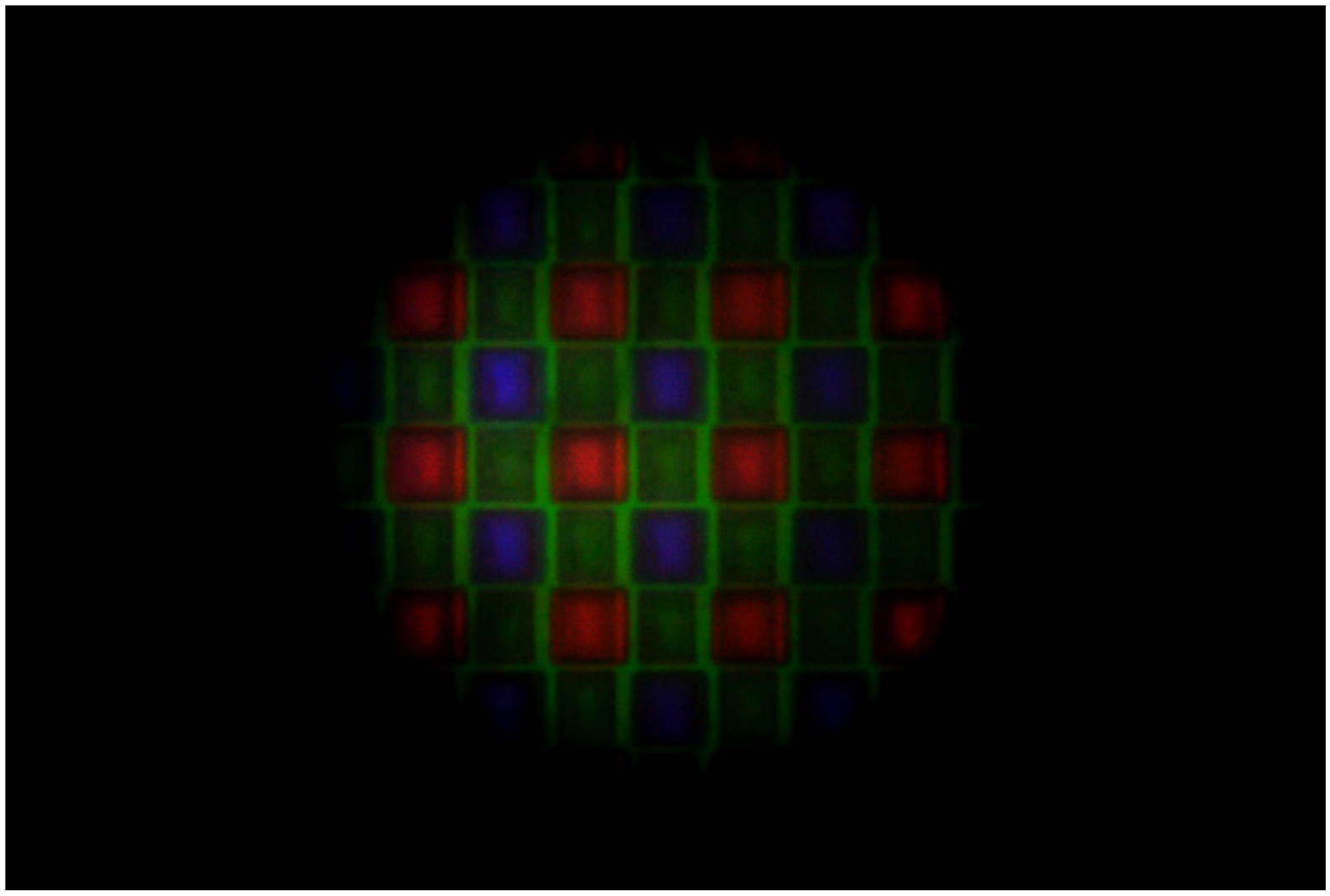
Bayer mosaic

Sensor



http://www.currentprotocols.com/WileyCDA/CPUnit/refId-ns0204.html

Microscope view of a CCD

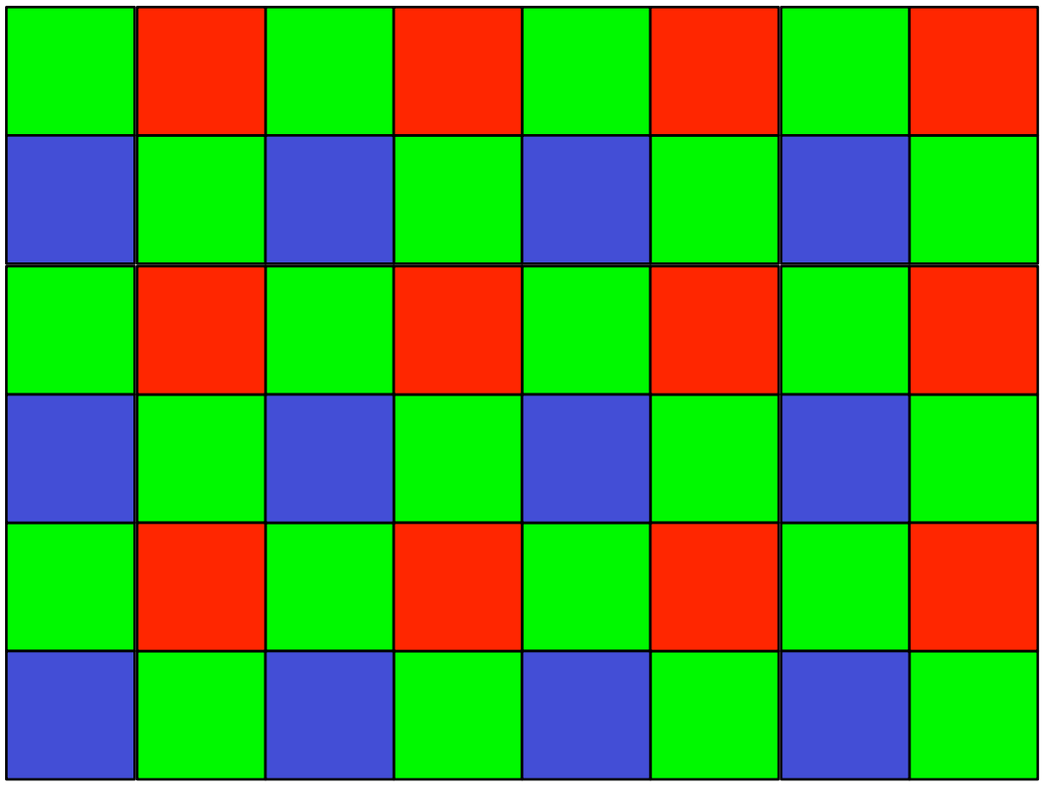


- By kevincollins123

http://www.flickr.com/photos/kevincollins123/4584180753/

Bayer RGB mosaic

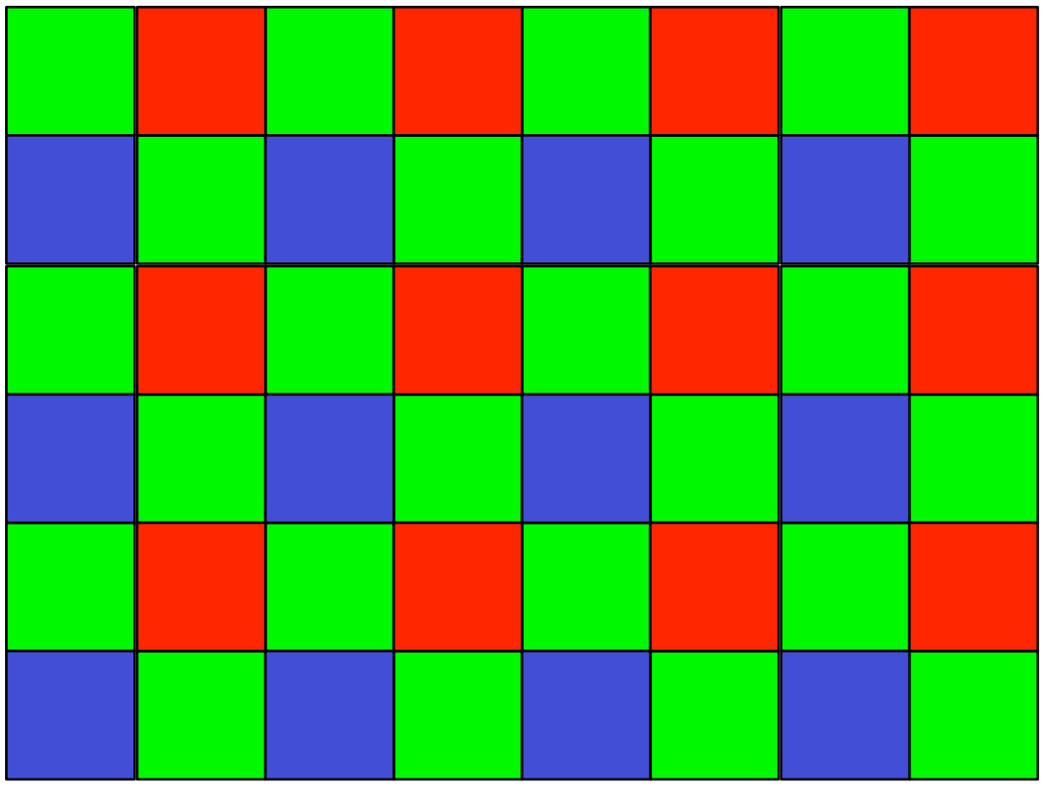
- Each photosite has a different color filter



Note that which one is the upper left color is arbitrary and depends on the camera

Bayer RGB mosaic

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



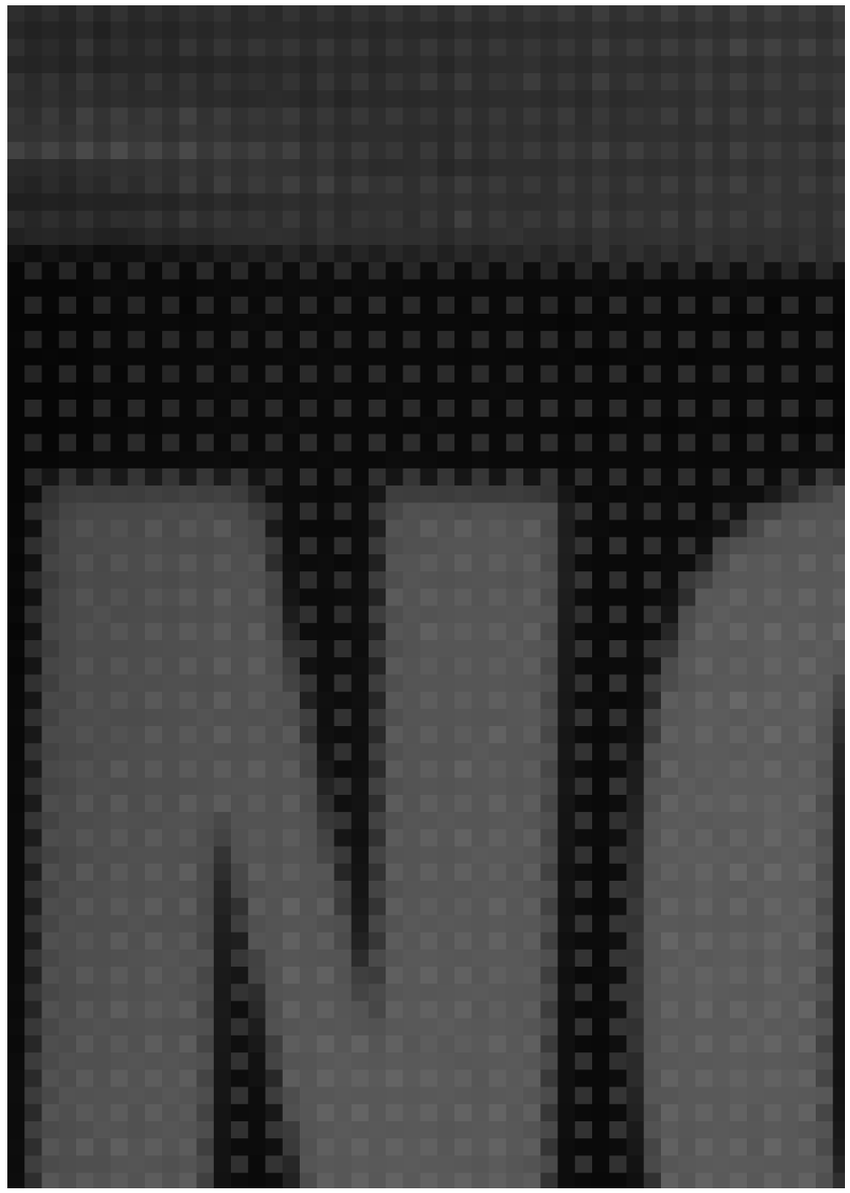
RAW files

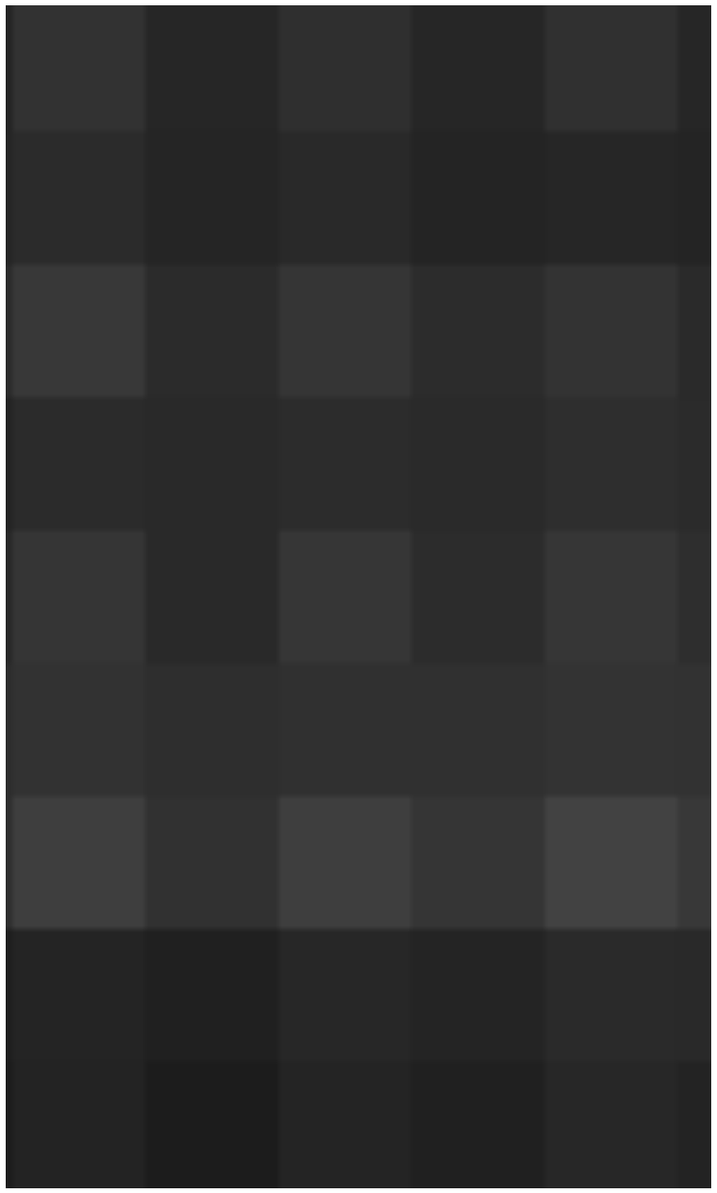
- **Straight measurement from sensor**
  - right after A/D conversion(well, kind of)
- **Each photosite has only one value**
  - Filtered by R, G or B
- **Usually 12-14 bits per pixel**
- **Linear encoding**
  - No gamma!
- **Can be read and converted using dcraw**
  - ./dcrawx86 -v -d pics/DSC_8274.nef
  - http://www.mit.edu/~kimo/blog/linear.html

A RAW file

- From a Nikon D70







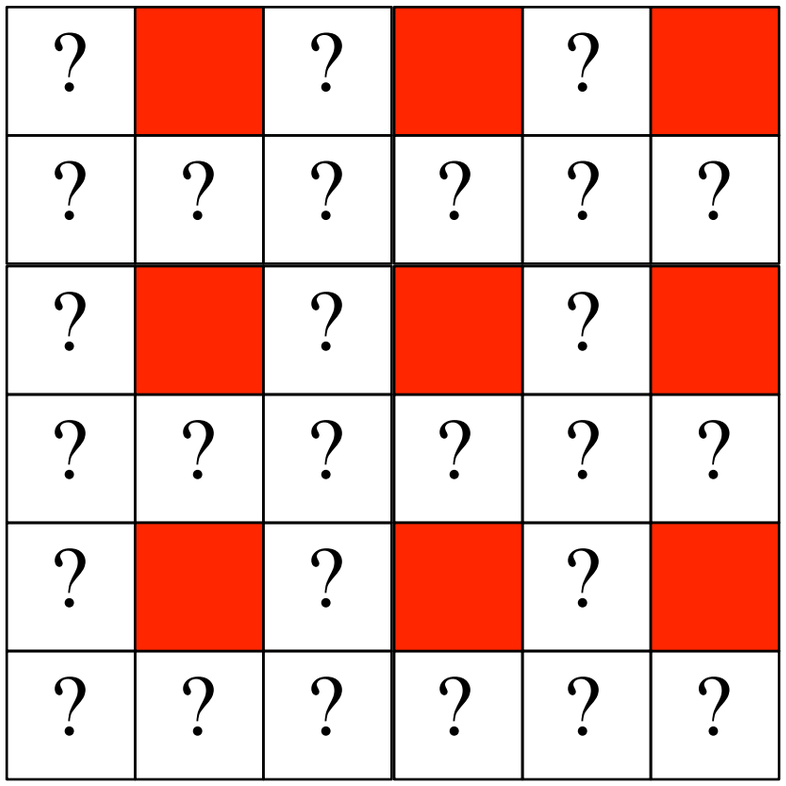
Questions?

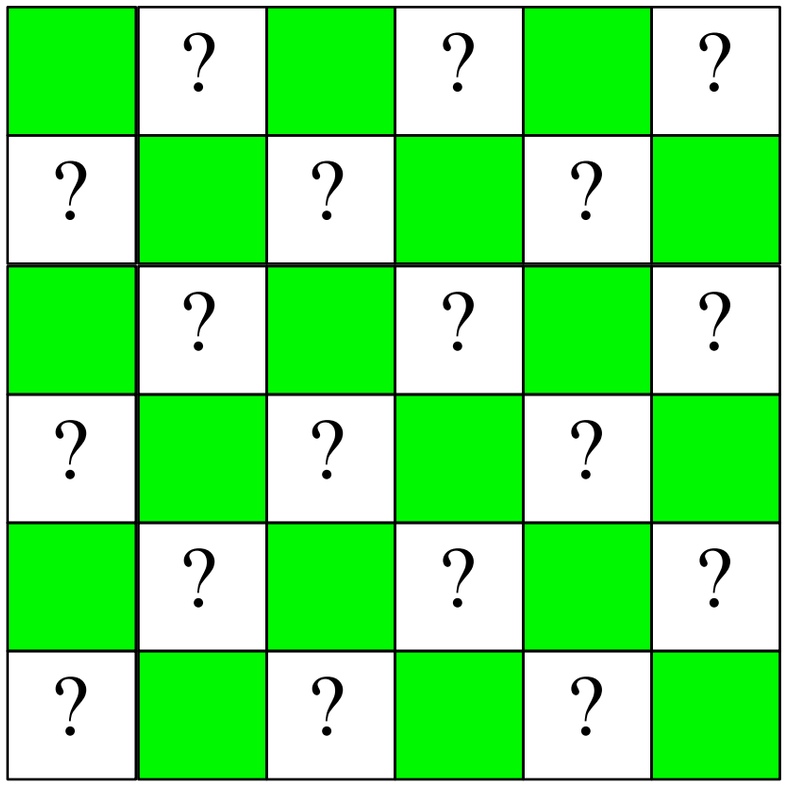


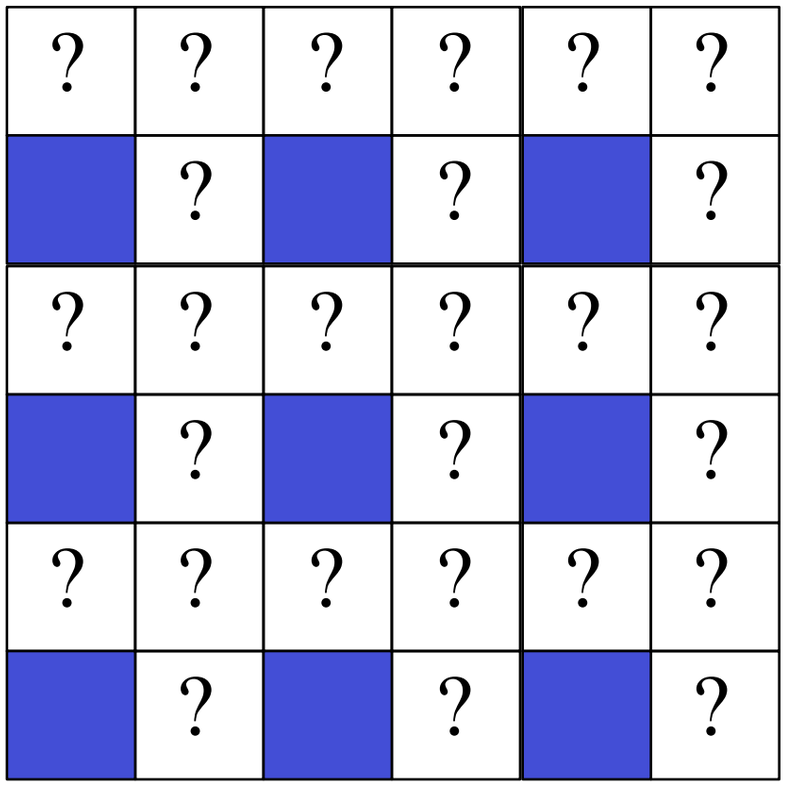
Demosaicking

Demosaicing

- Interpolate missing values

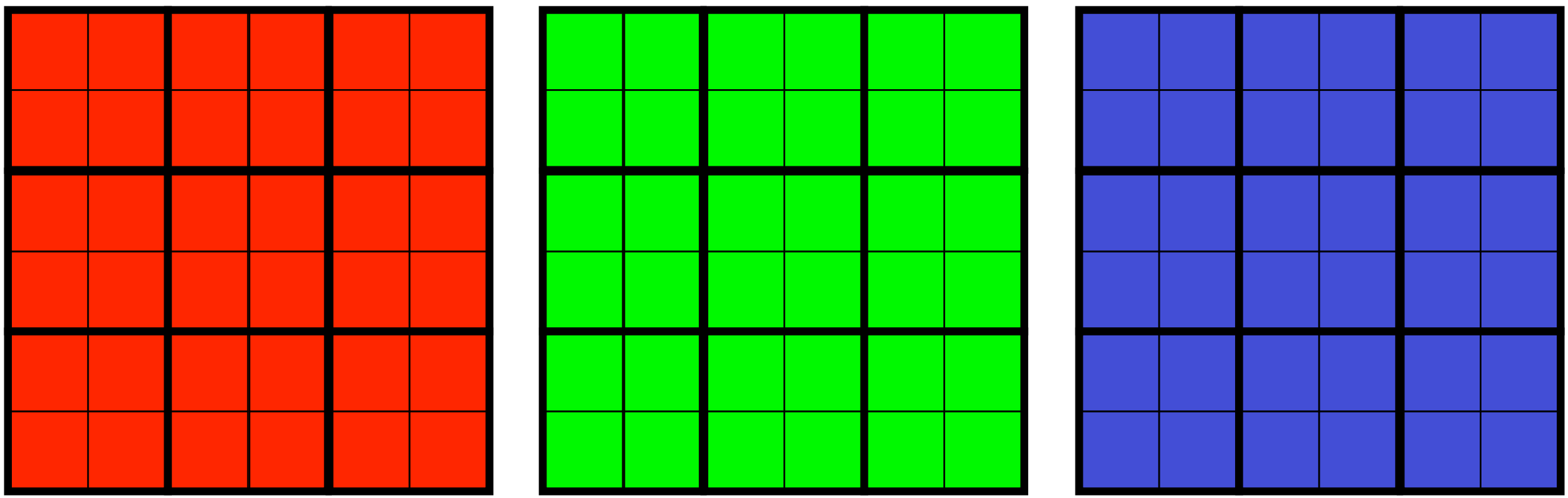






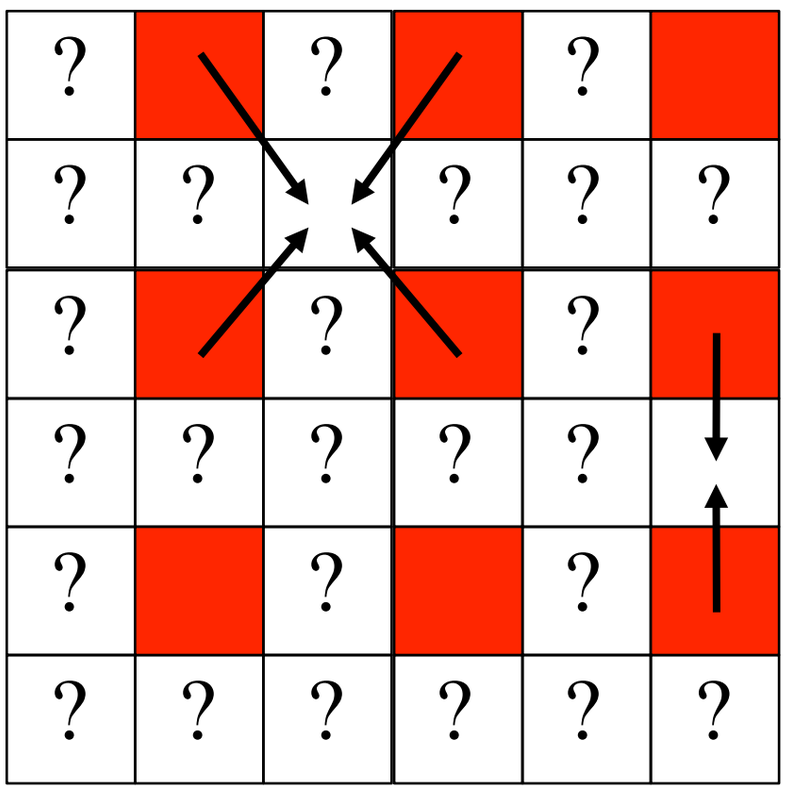
Demosaicing

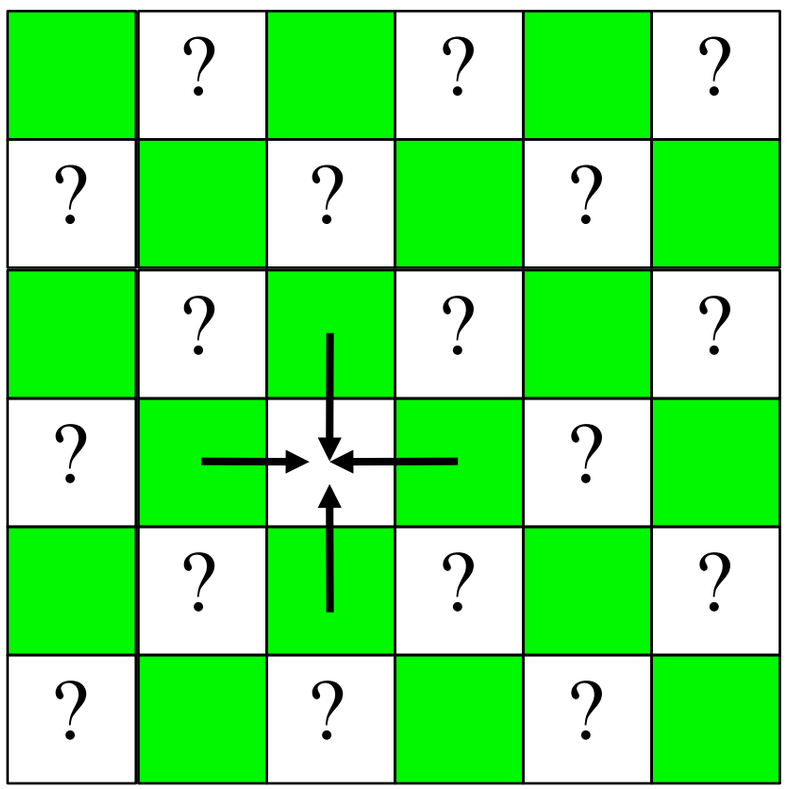
- Simplest solution: downsample!
  - Nearest-neighbor reconstruction
  - Problems:
    - resolution loss
    - color artifacts at edges

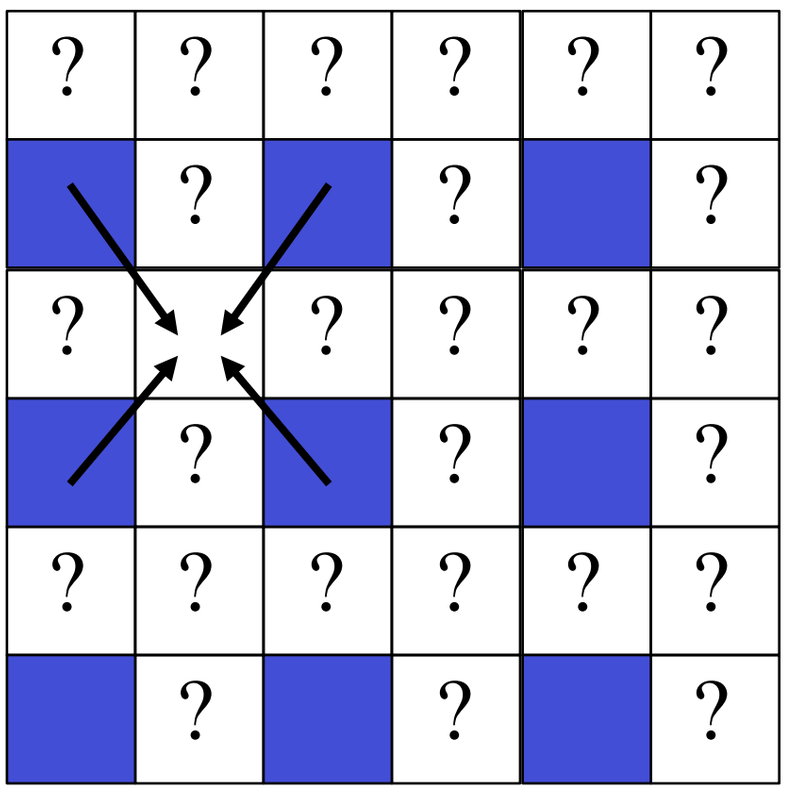


Linear interpolation

- Average of the 4 or 2 nearest neighbors
  - Linear (tent) kernel
- For example:
  newgreen=

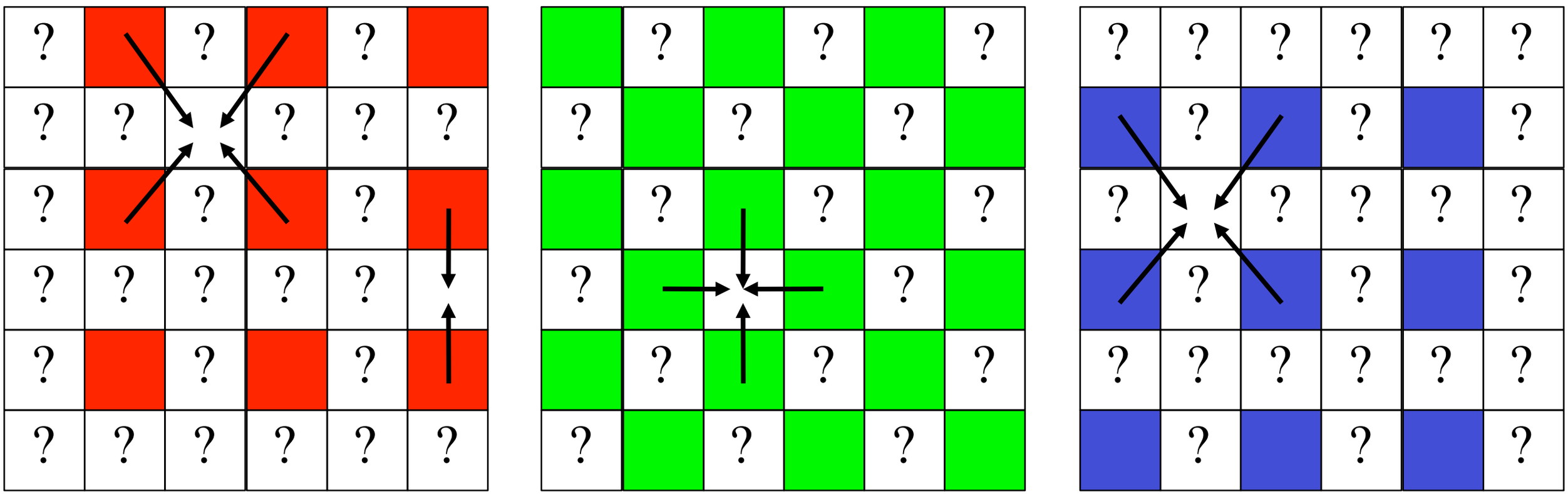






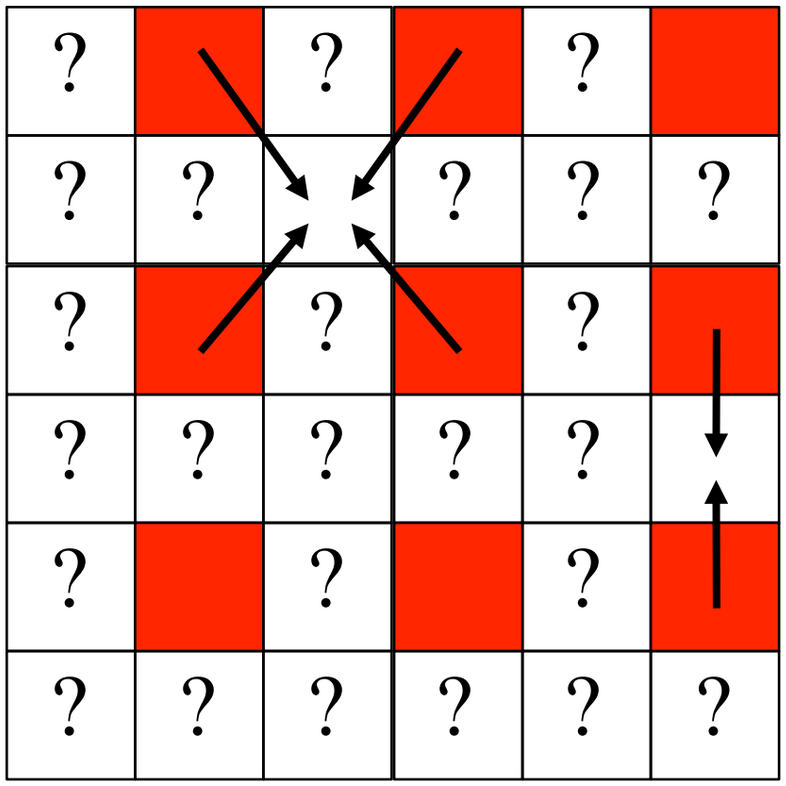
Linear interpolation

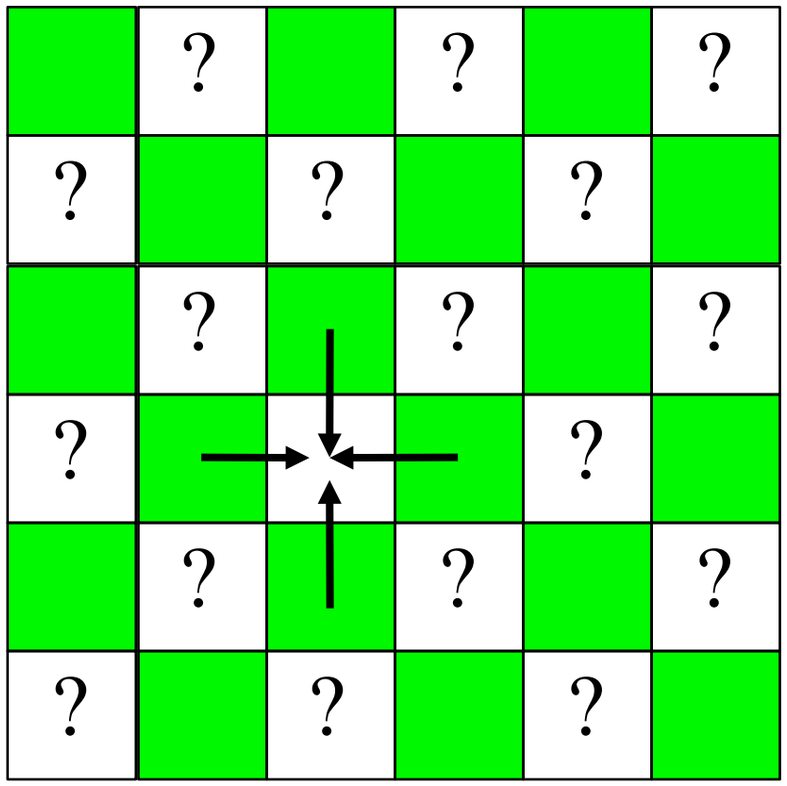
- Average of the 4 or 2 nearest neighbors
  - Linear (tent) kernel
- For example:
  newgreen=0.25(up+left+right+down)

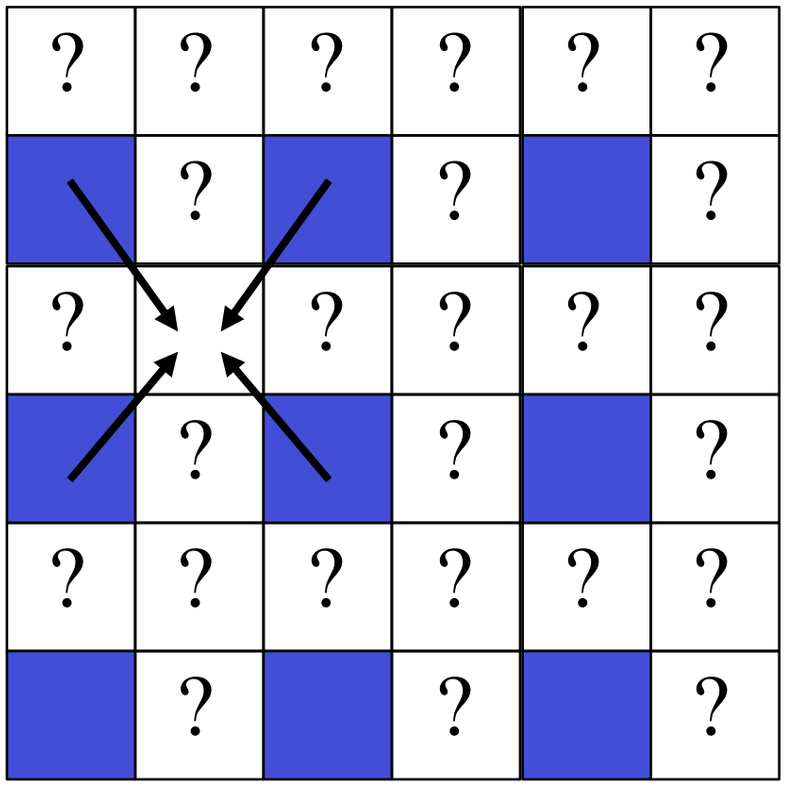


Better

- Smoother kernels can also be used (e.g. bicubic) but need wider support





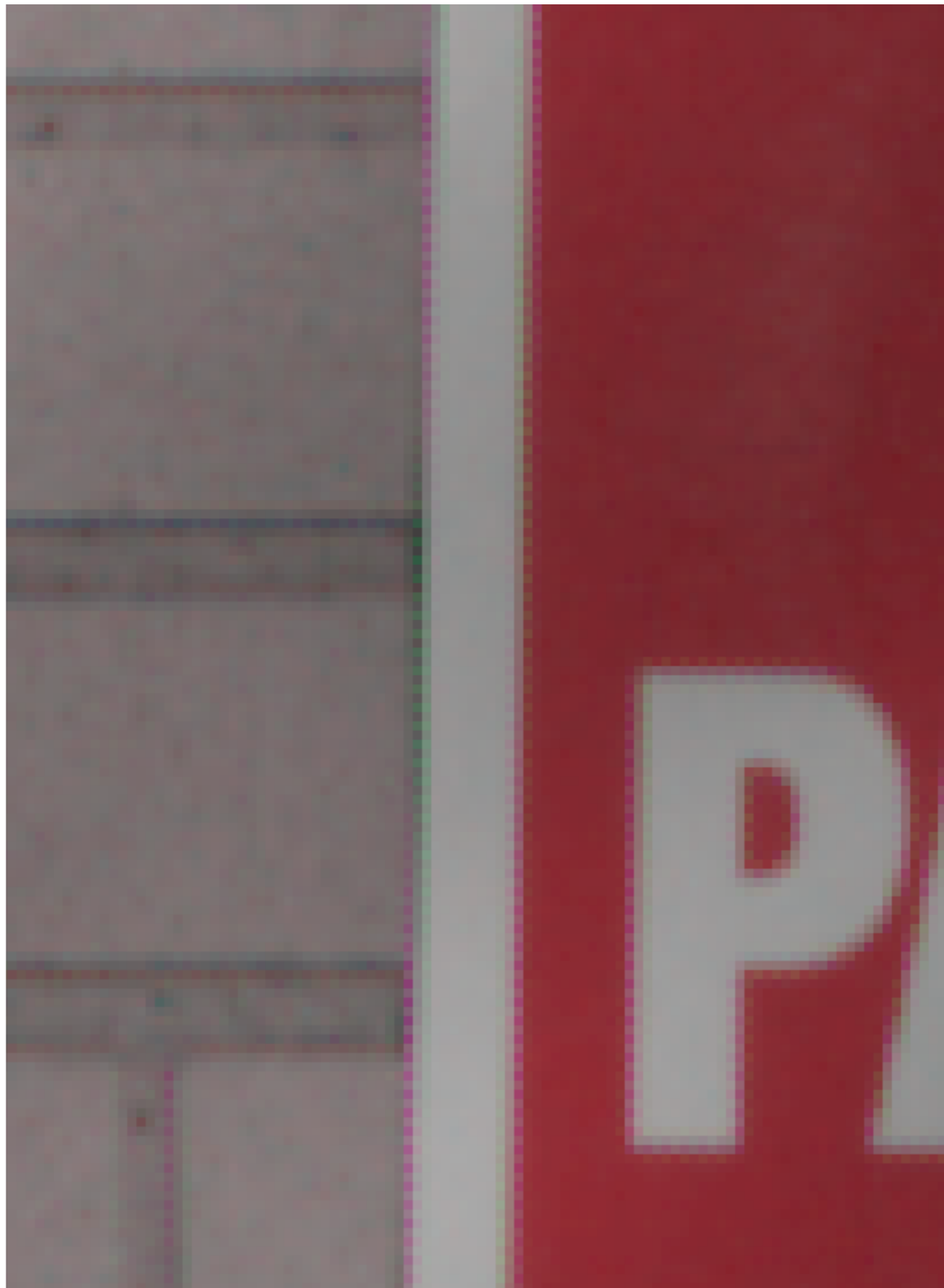


Results of simple linear



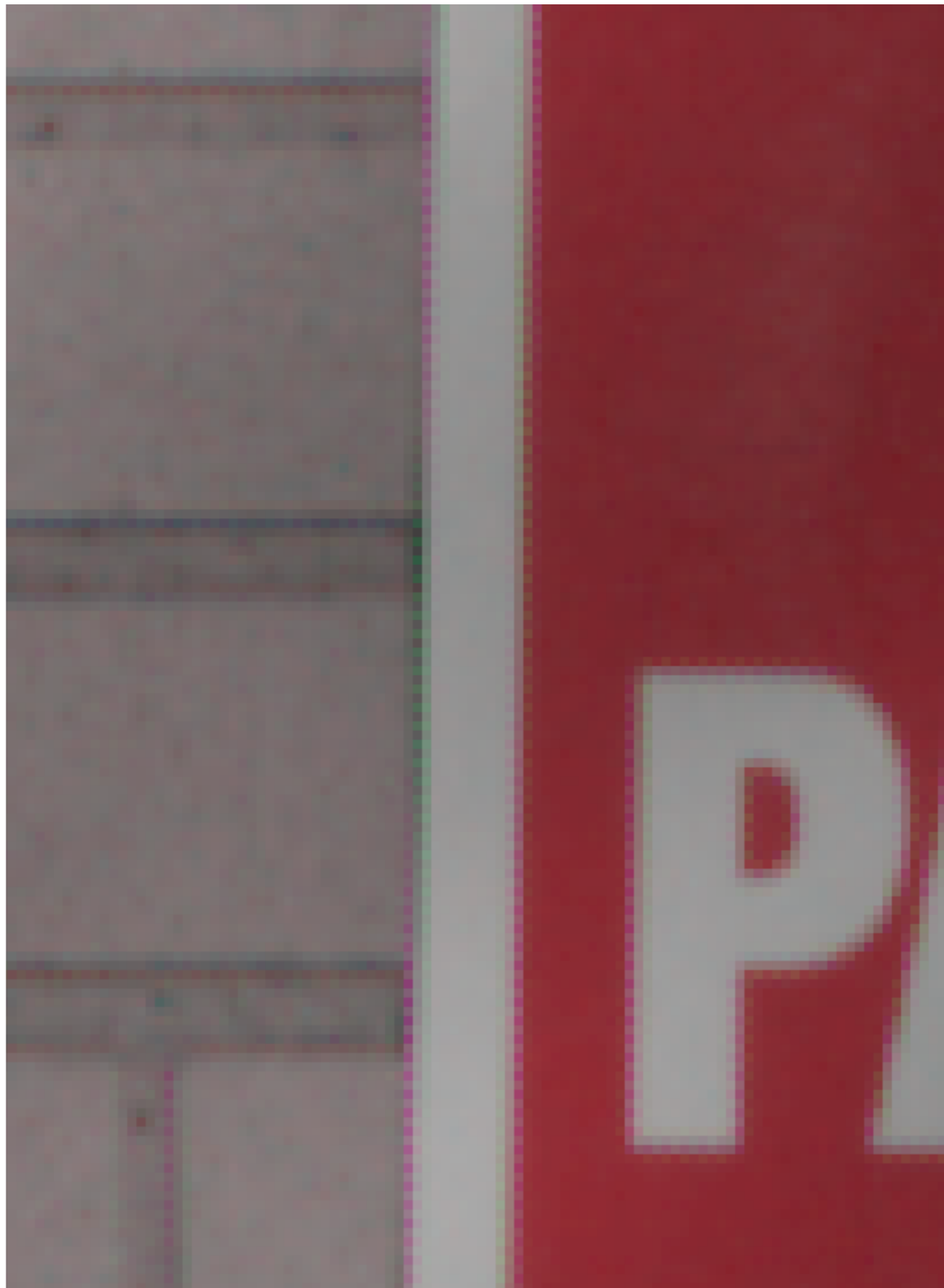
Results - not perfect





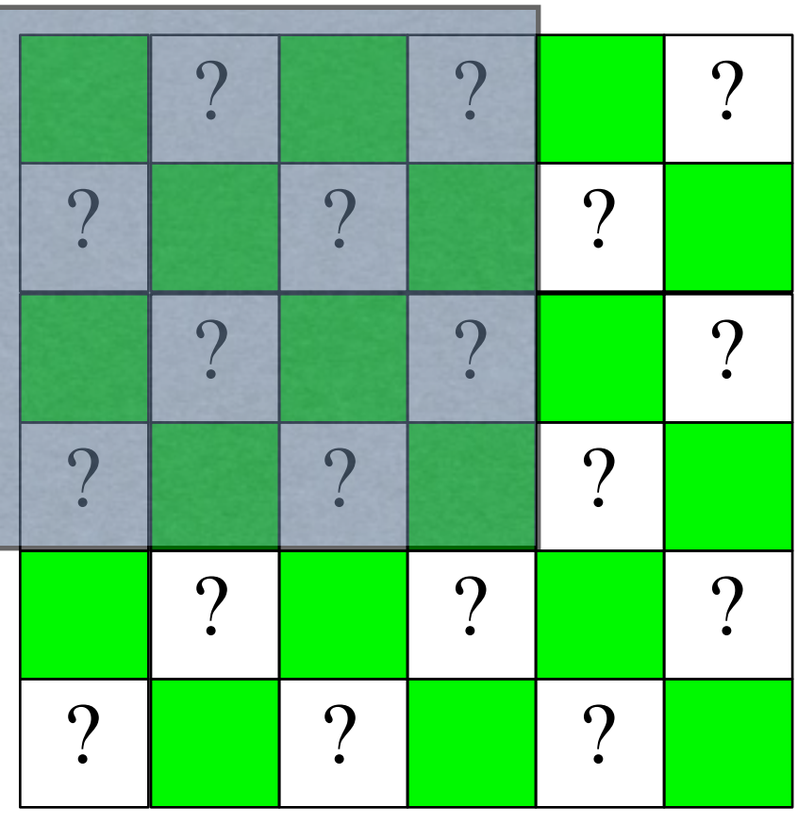
Questions?





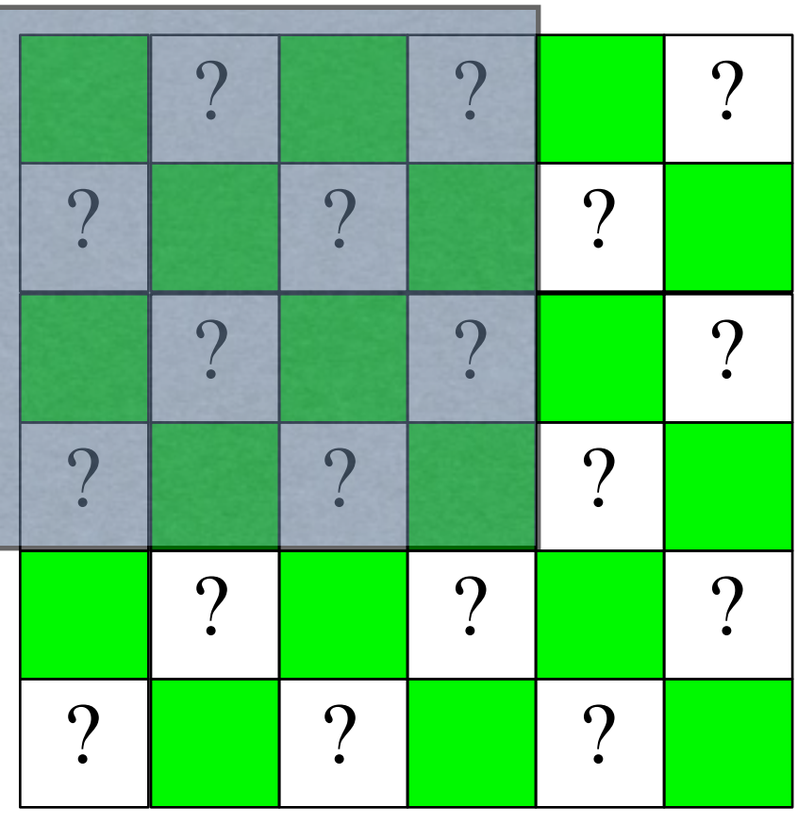
The problem

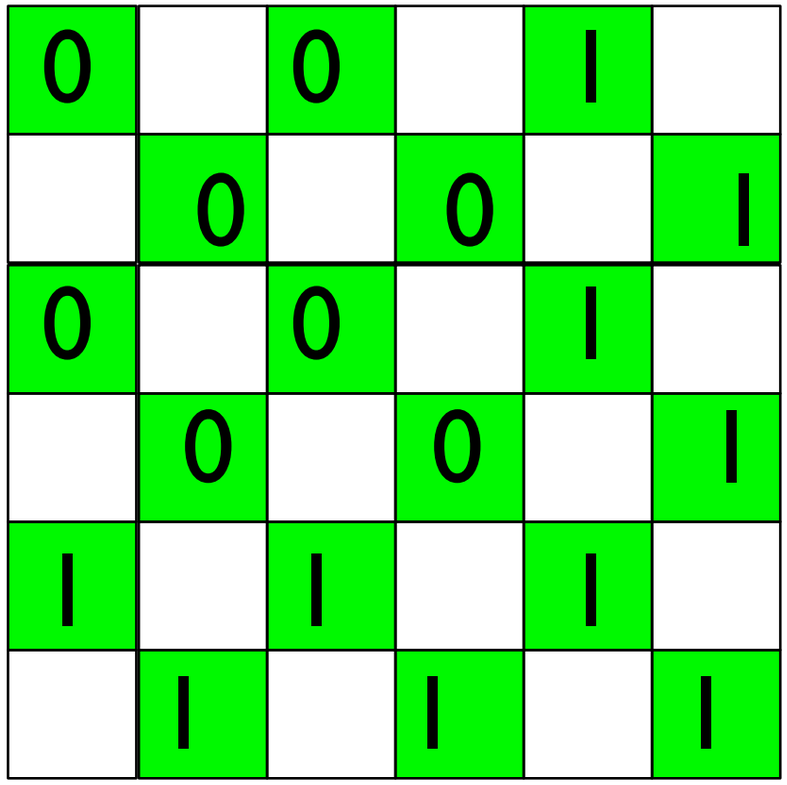
- Imagine a black-on-white corner
- Let’s focus on the green channel for now



The problem

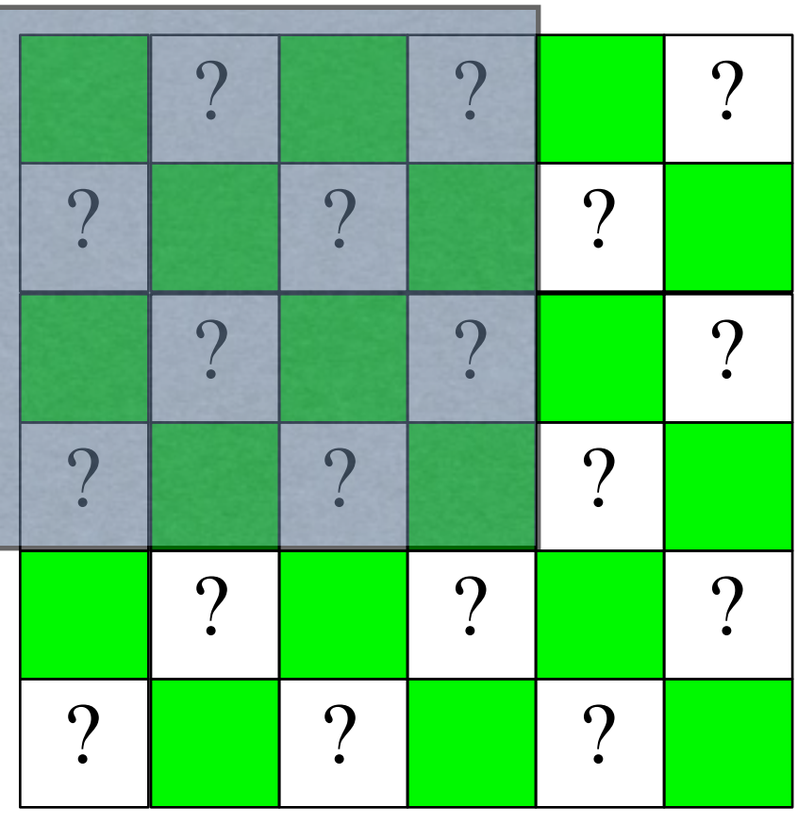
- Imagine a black-on-white corner

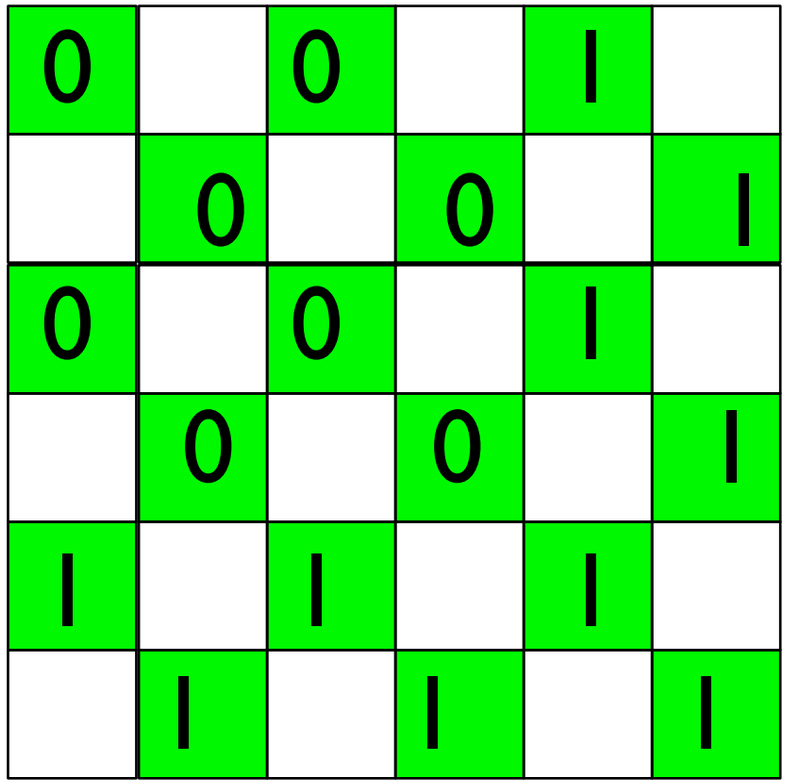


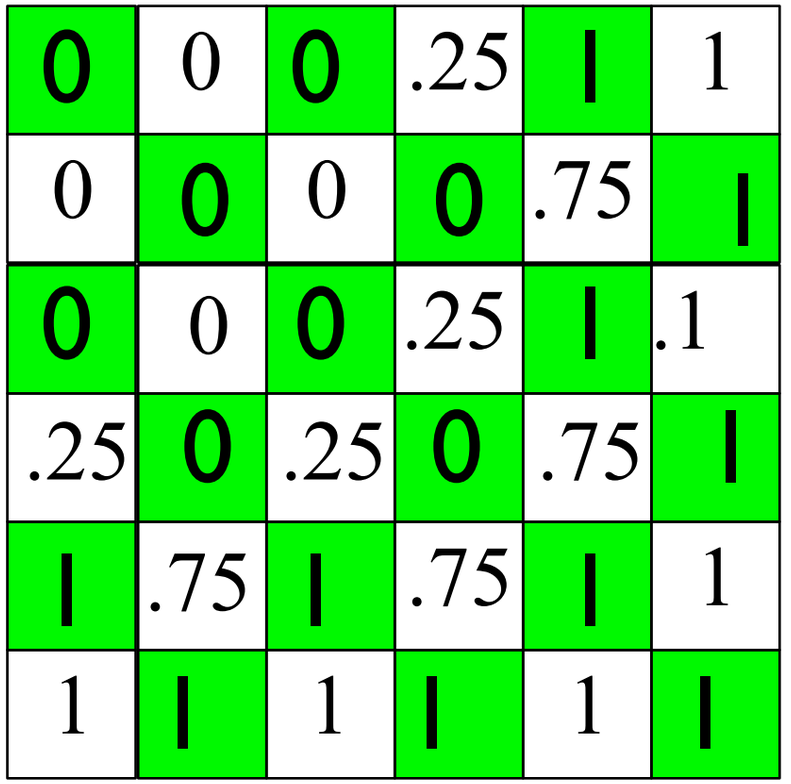


The problem

- Imagine a black-on-white corner

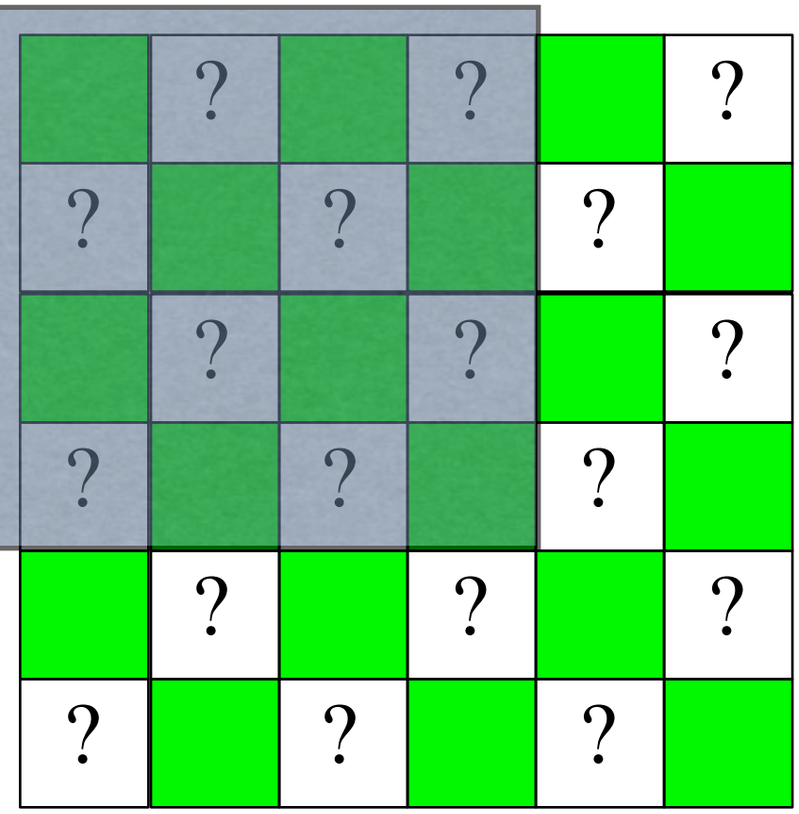


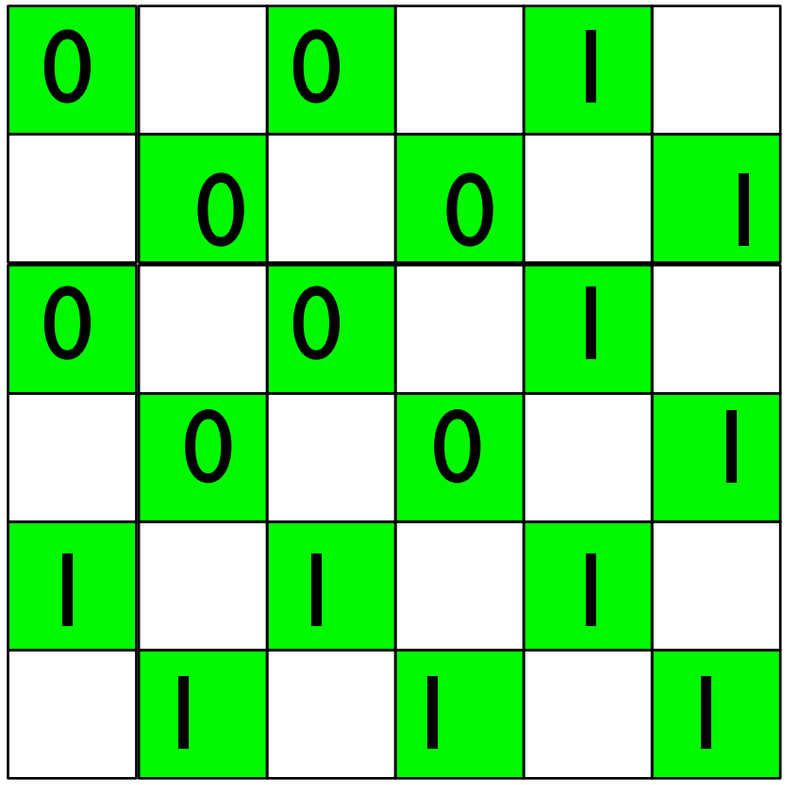


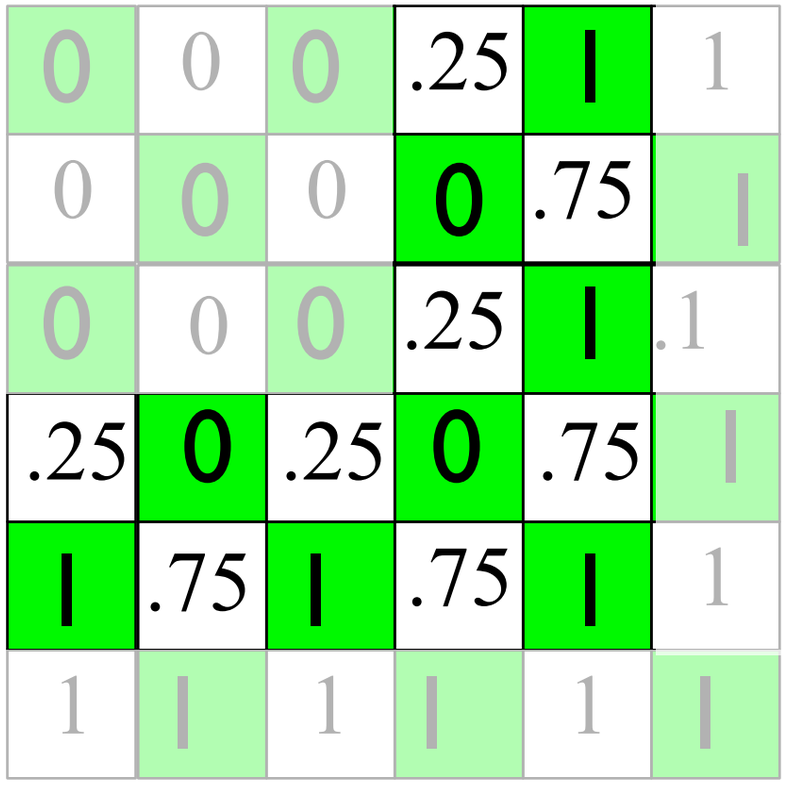


The problem

- Imagine a black-on-white corner







Yep, that’s what we saw



Green channel



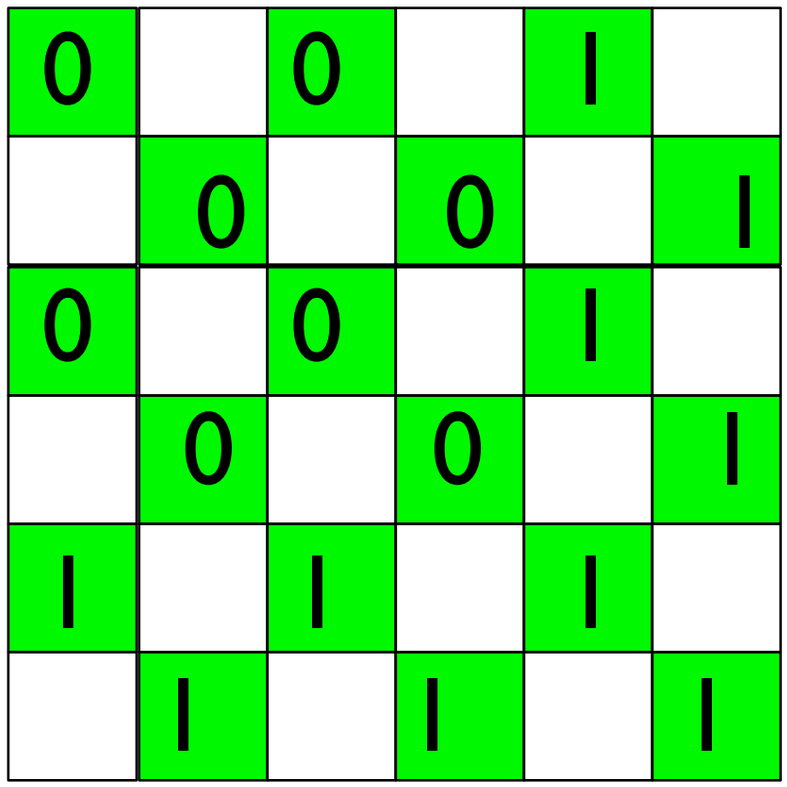
Questions?



Edge-based Demosaicking

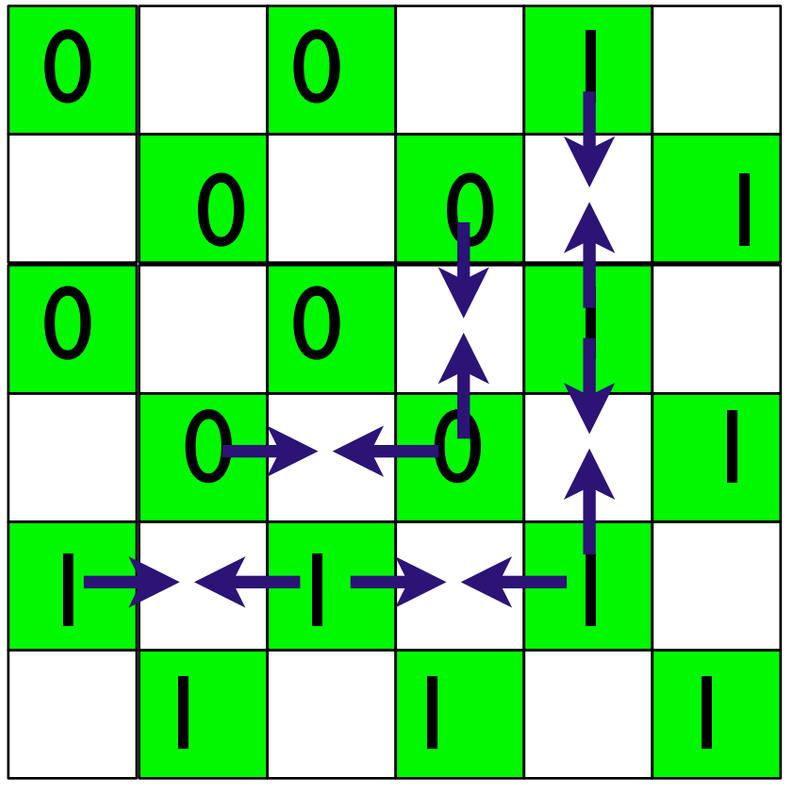
Idea

- **Take into account structure in image**
  - Here, 1D edges
- **Interpolate along preferred direction**
  - In our case, only use 2 neighbors



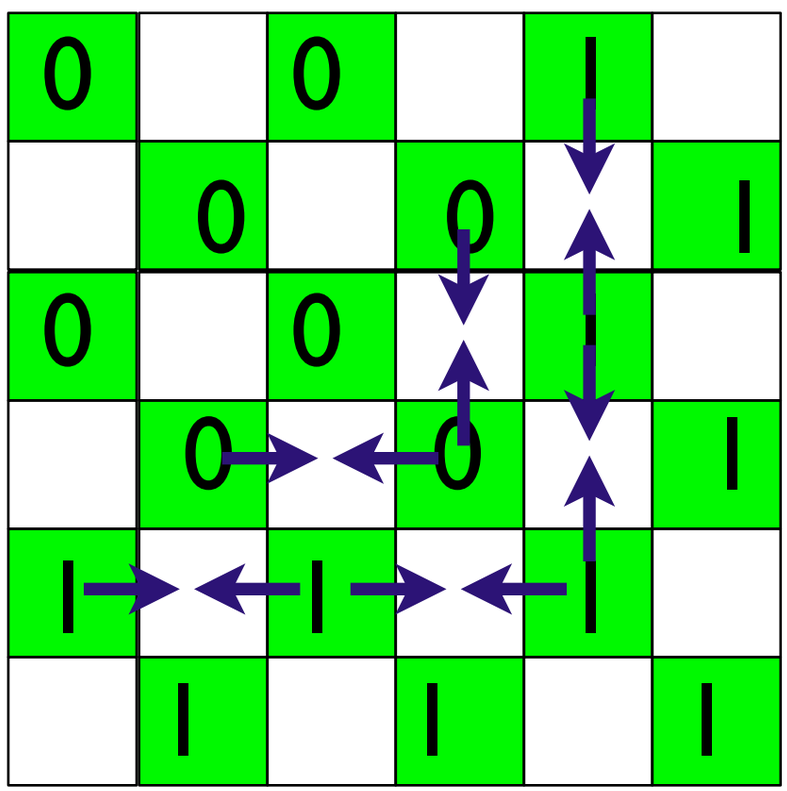
Idea

- **Take into account structure in image**
  - Here, 1D edges
- **Interpolate along preferred direction**
  - In our case, only use 2 neighbors



How do we decide

- Look at the similarity of recorded neighbors
  - Compare lup-downl and lright-leftl
  - Be smart
  - See pset 4
- Called edge-based demosaicking



Green channel -- naive



Green channel -- edge-based




100 PUZZLE

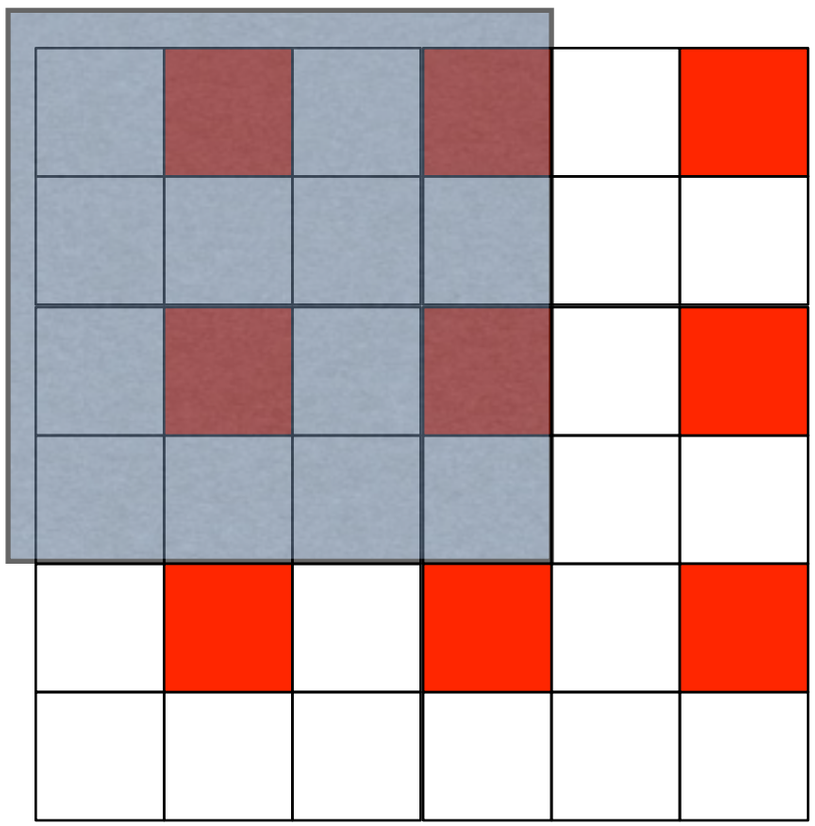
Challenge with other channels

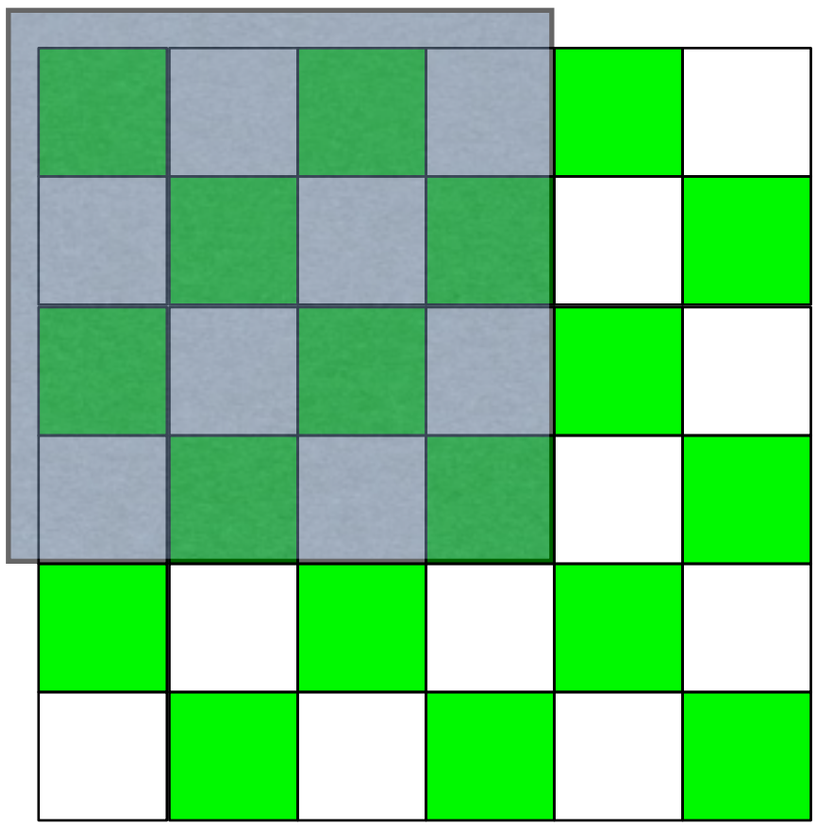
Problem

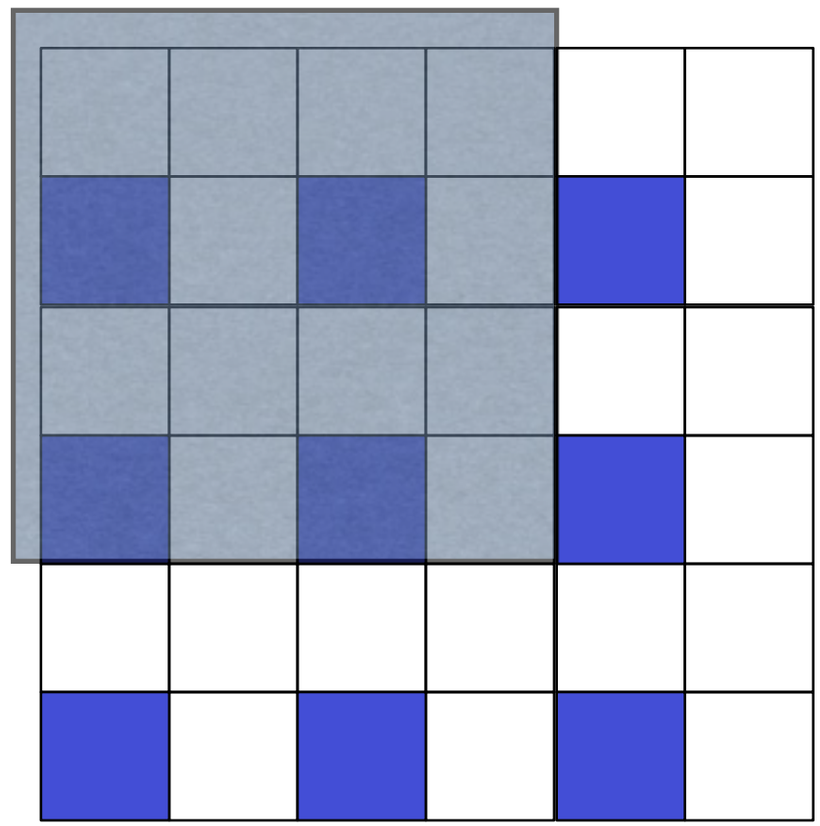
- What do we do with red and blue?
- We could apply the edge-based principle
- But we’re missing more information
- But color transitions might be shifted

Example

- Black on white corner
- Even if we imagine we can do some decent job for each channel

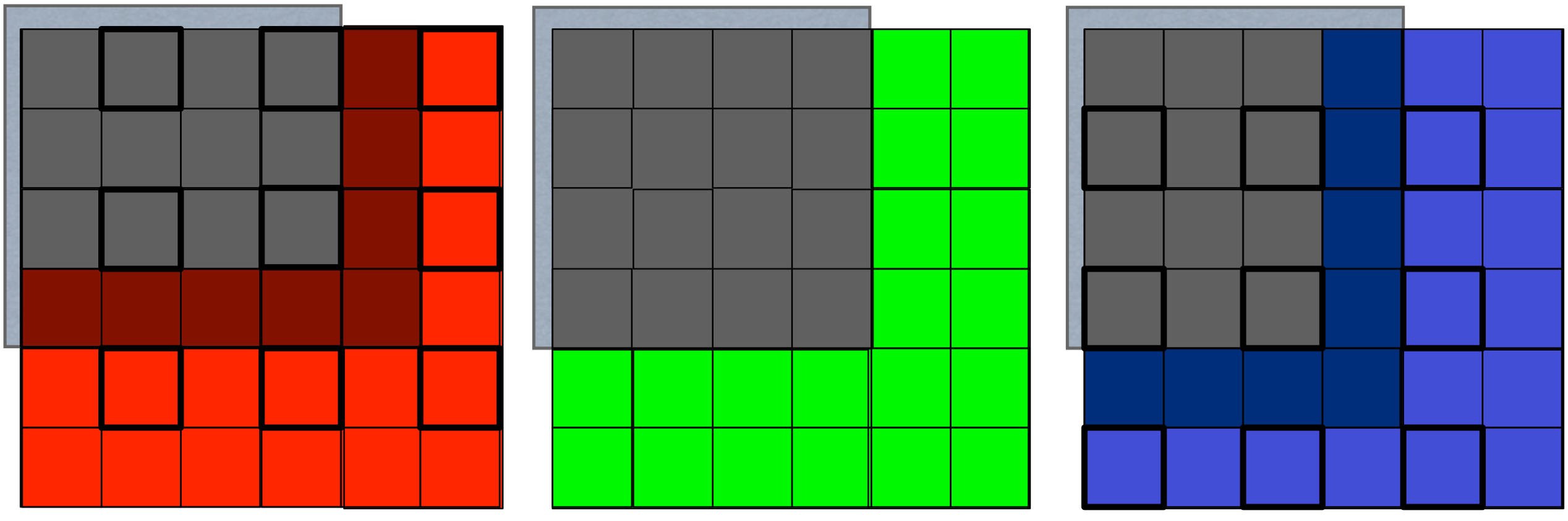






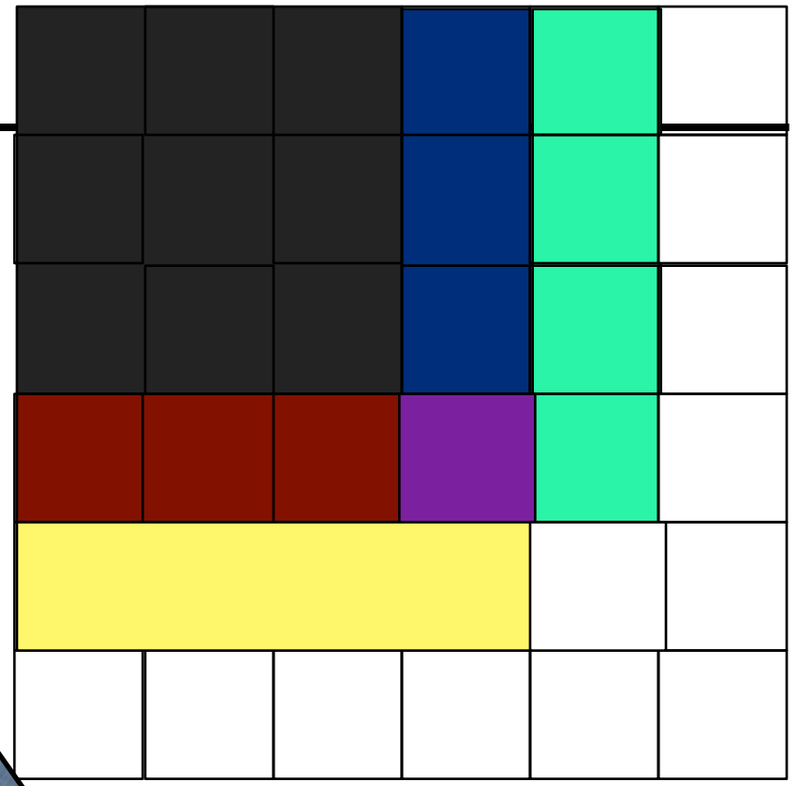
Example

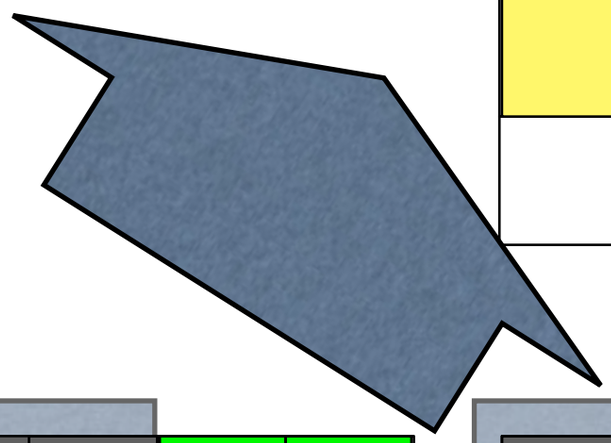
- Black on white corner
- Even if we imagine we can do some decent job for each channel
- The channels don’t line up
  - Because they are not recorded at the same location

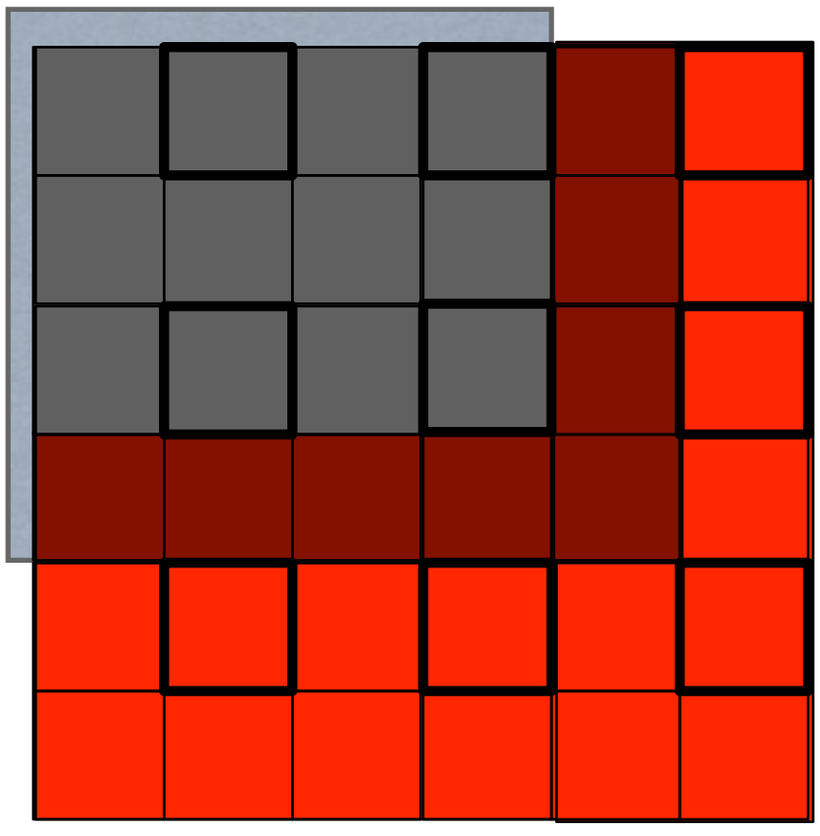


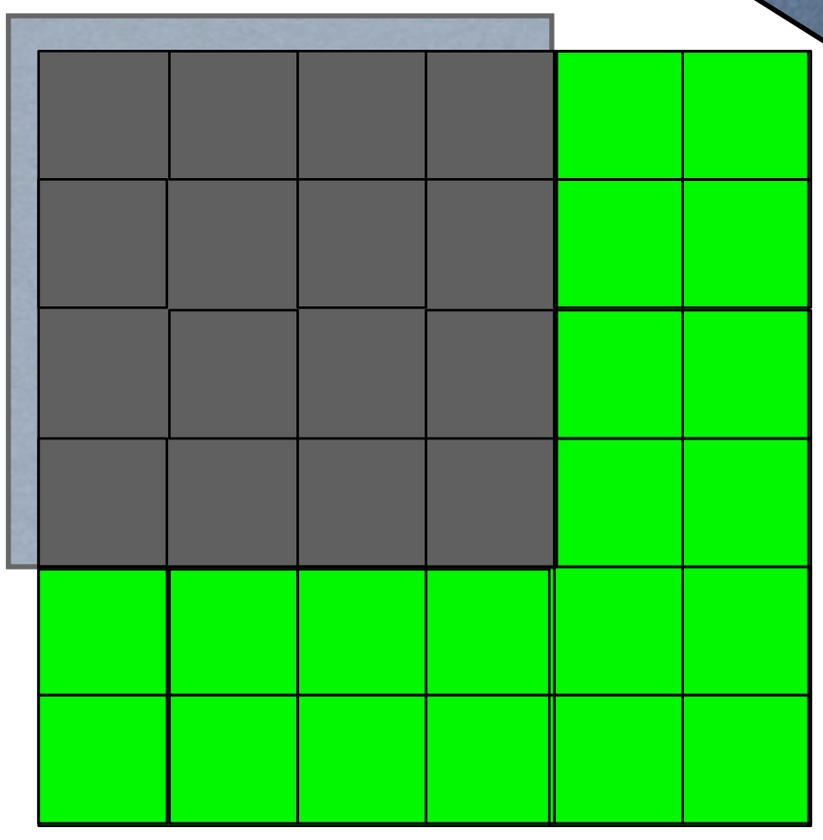
Example

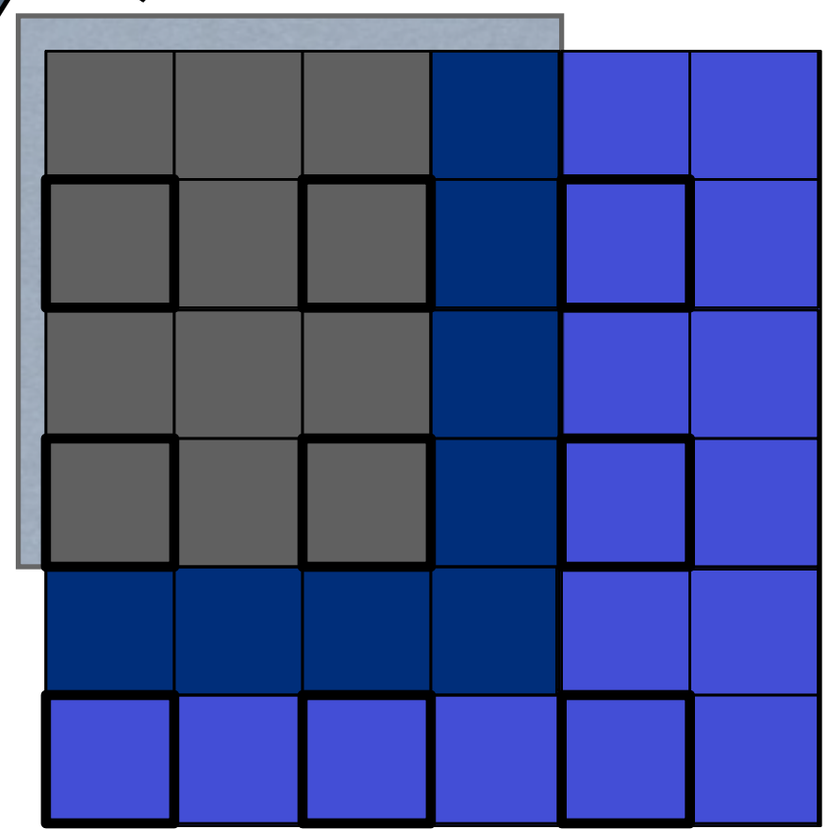
- Bad color fringes!











Recall color artifacts



Questions?



Green-based Demosaicking

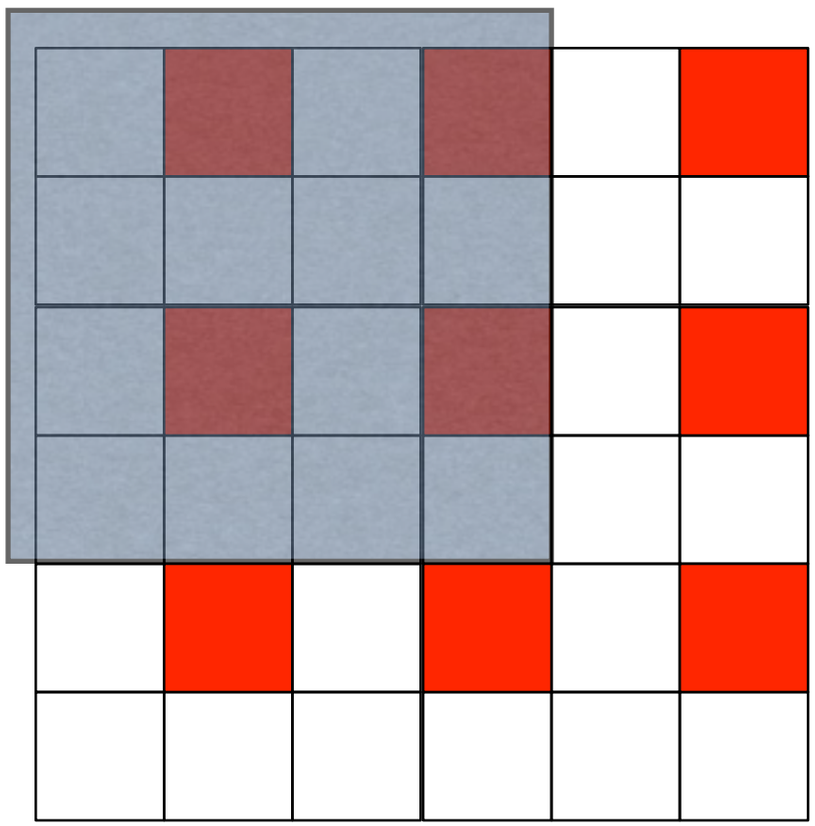
Green-based demosaicking

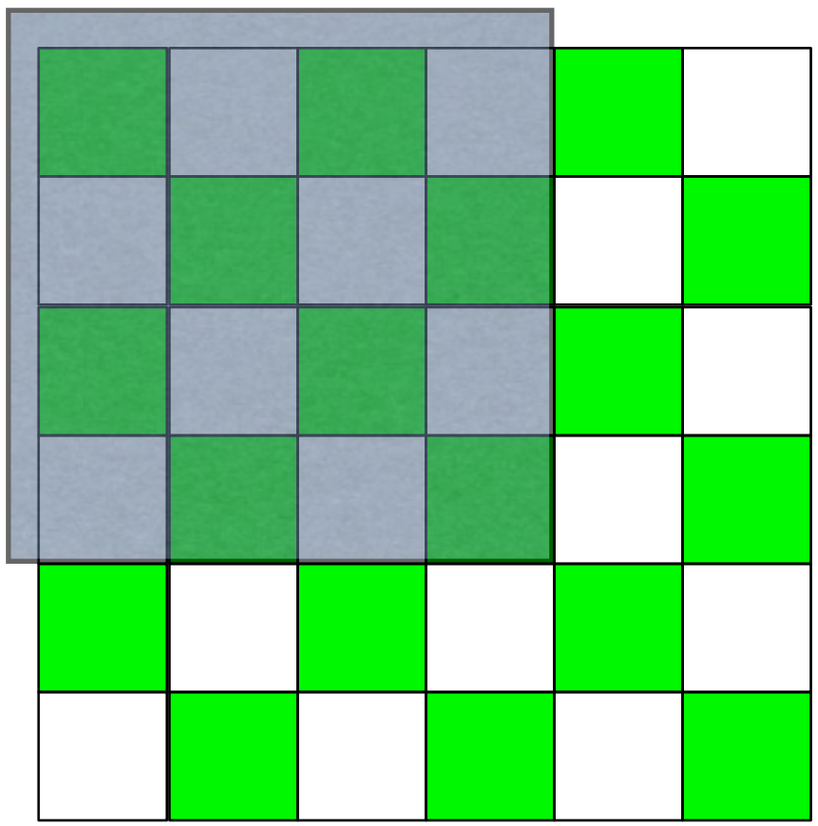
- Green is a better color channel
  - Twice as many pixels
  - Often better SNR
  - We know how to do edge-based green interpolation
- Do the best job you can and get high resolution from green
- Then use green to guide red & blue interpolation

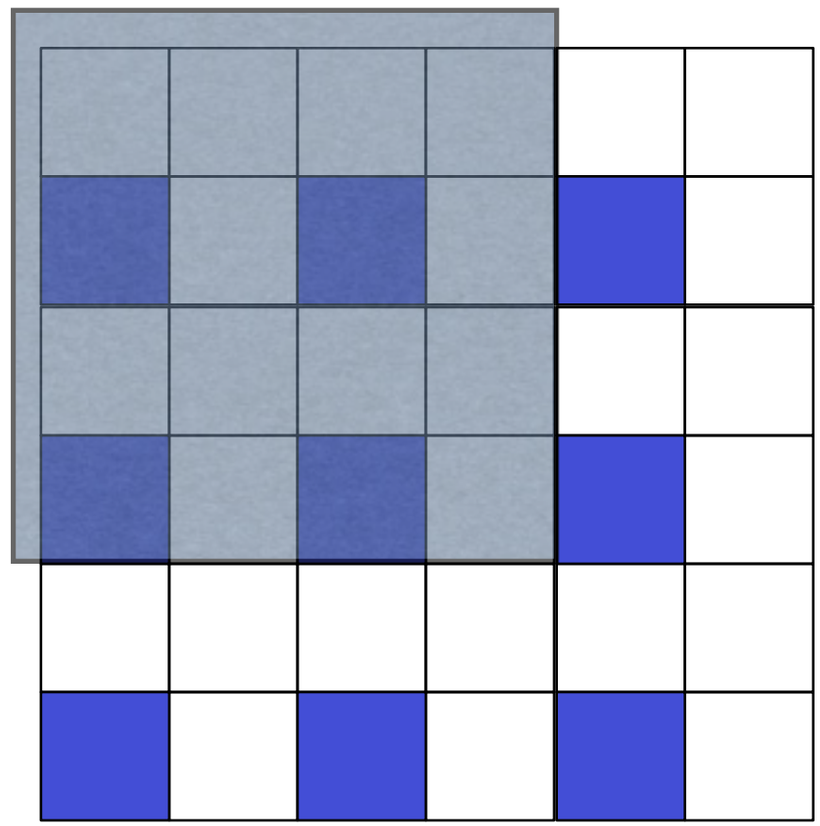
Interpolate difference to green

- Interpolate green
  - using e.g. edge-based
- For recorded red pixels
  - compute R-G
- At empty pixels
  - Interpolate R-G naively
  - Add G
- Same for blue

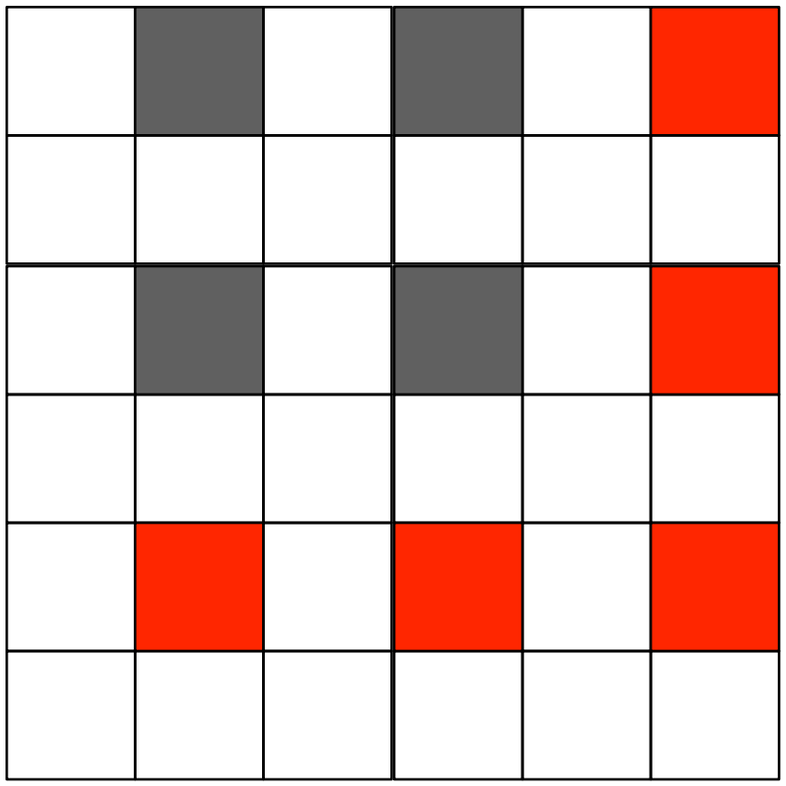
Black on white corner

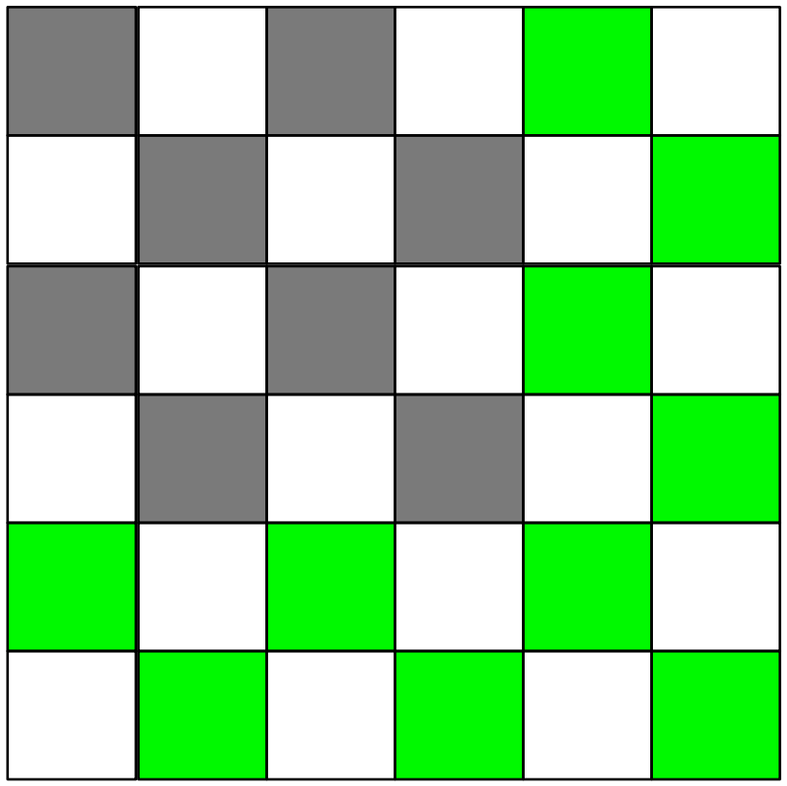


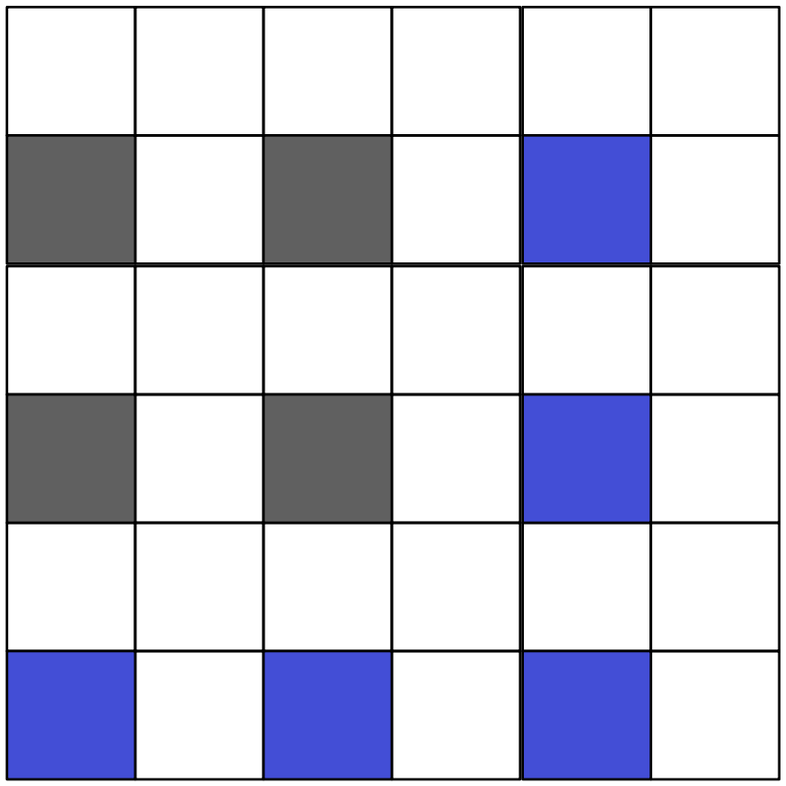




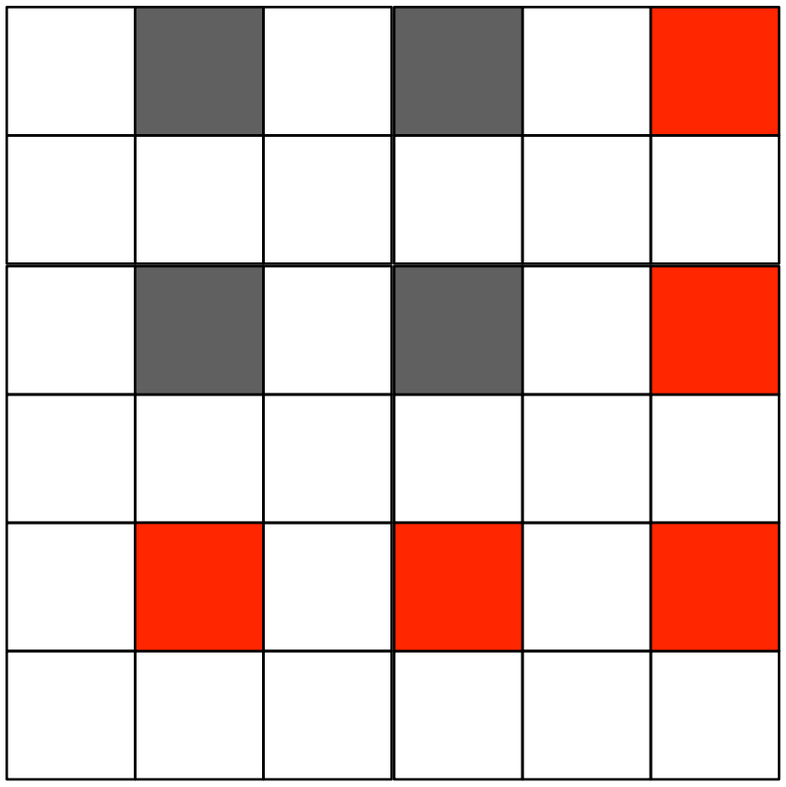
Measurements

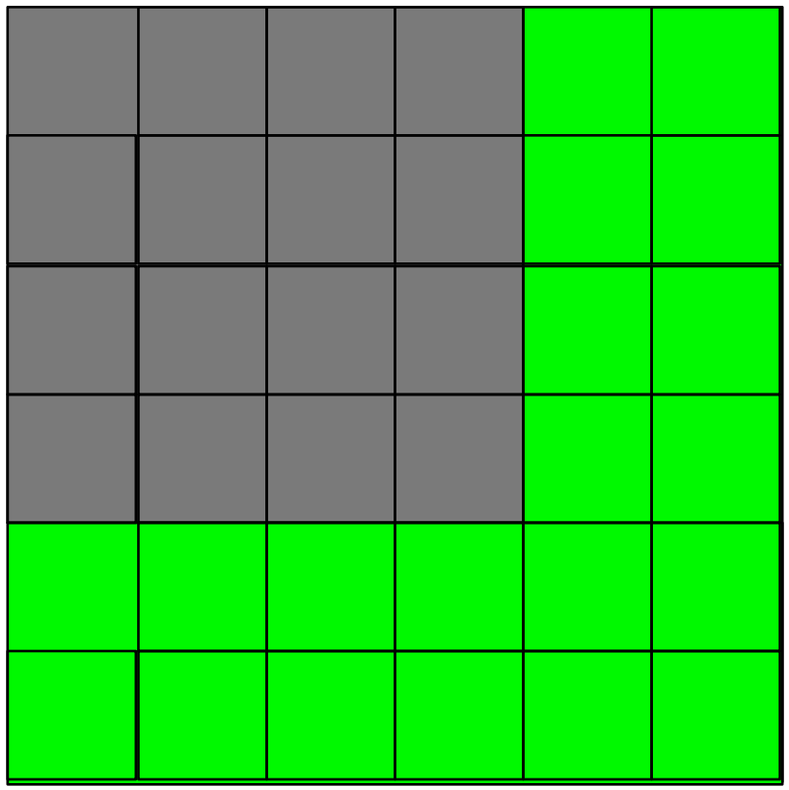


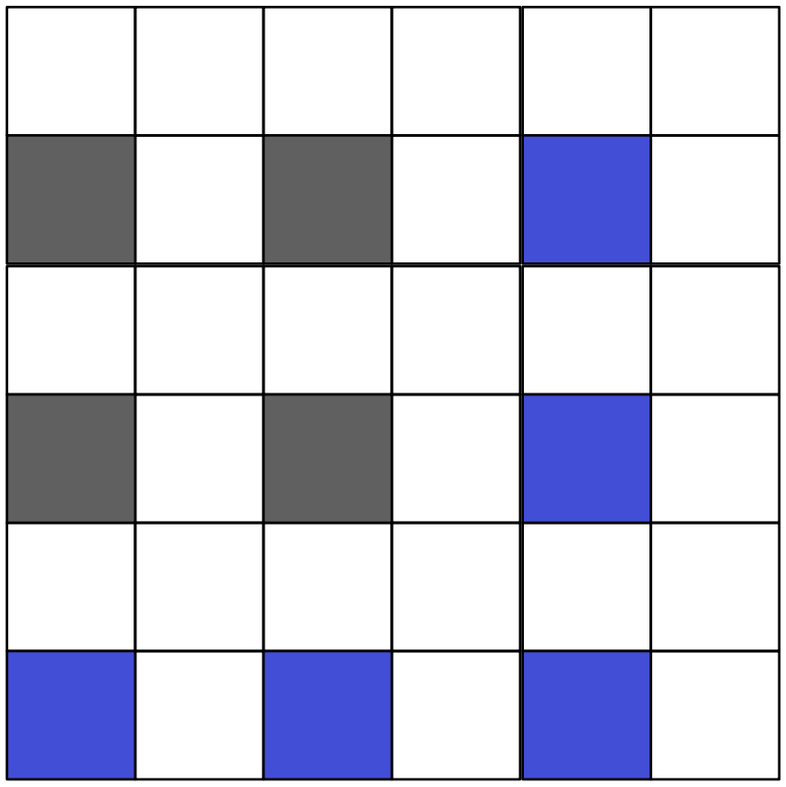




Edge-based green

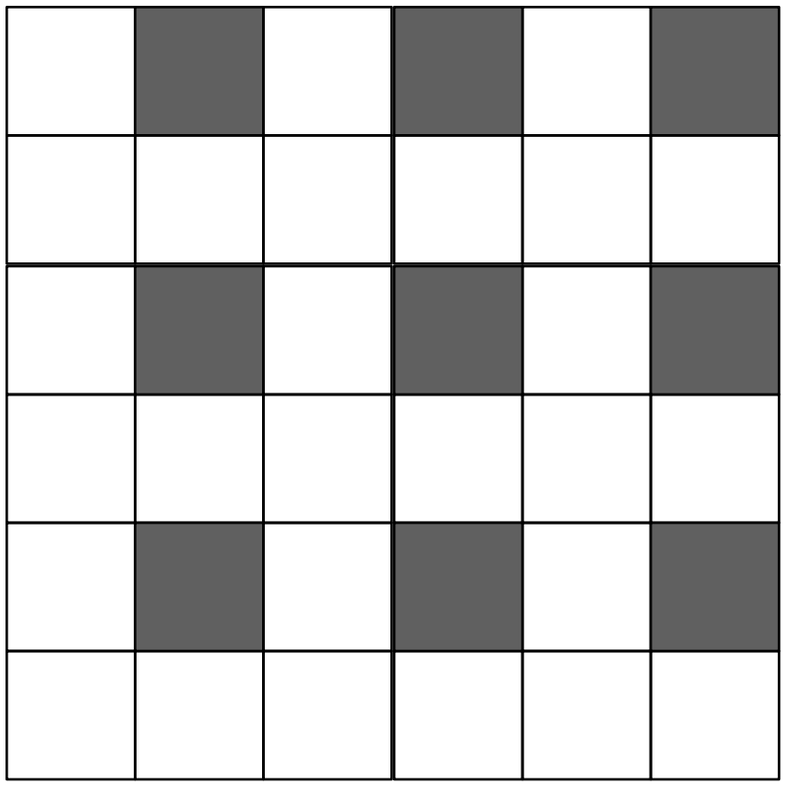


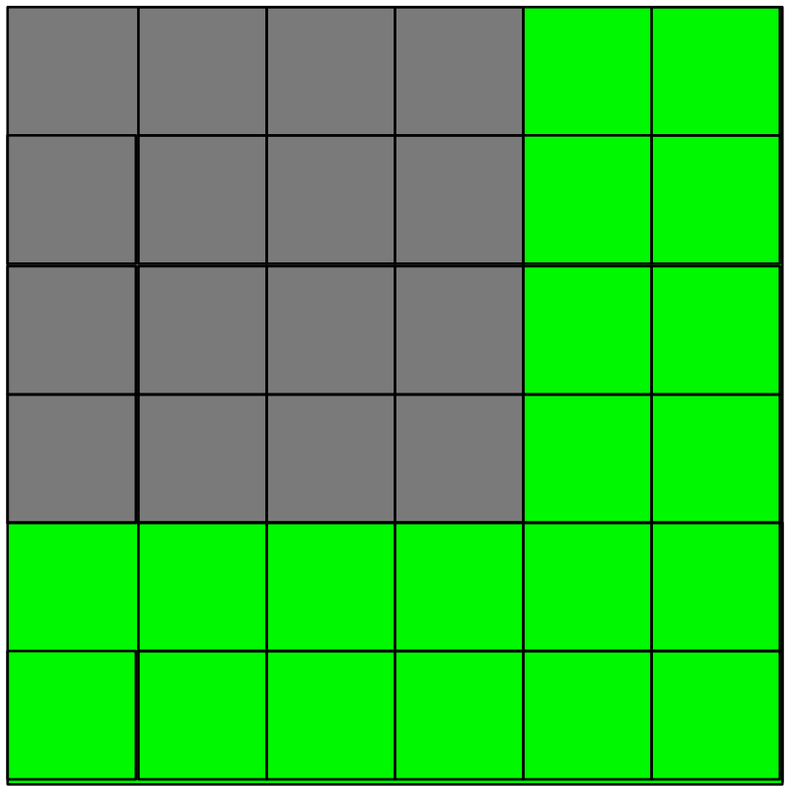


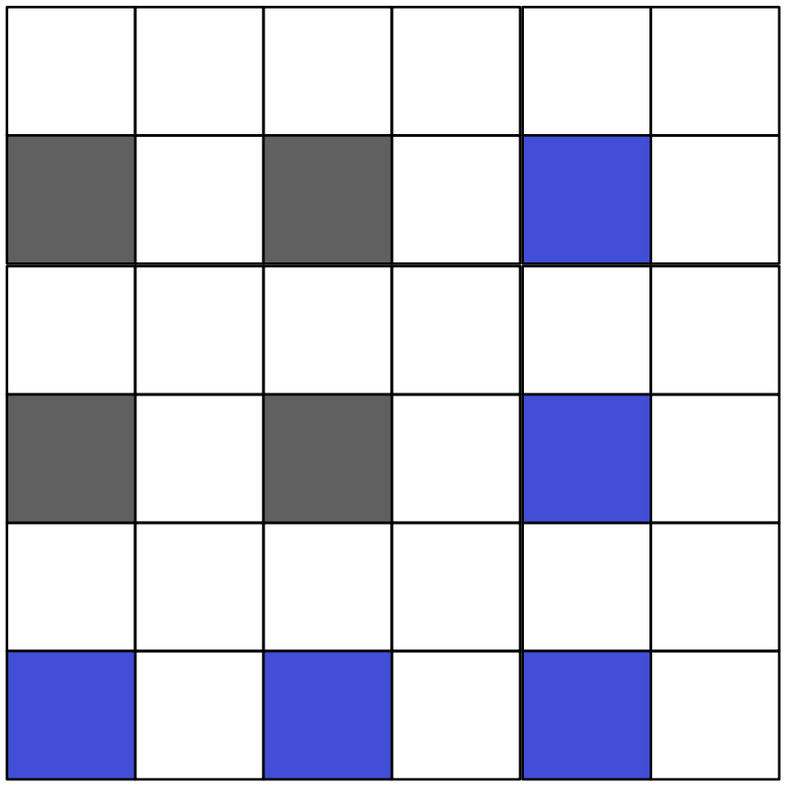


Red-Green difference

- Zero everywhere!

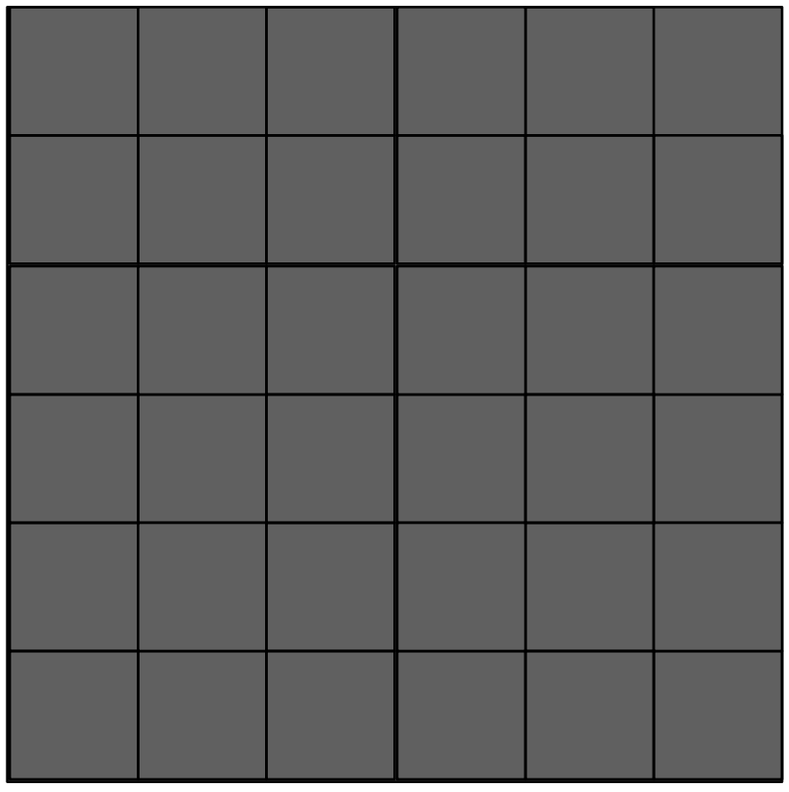


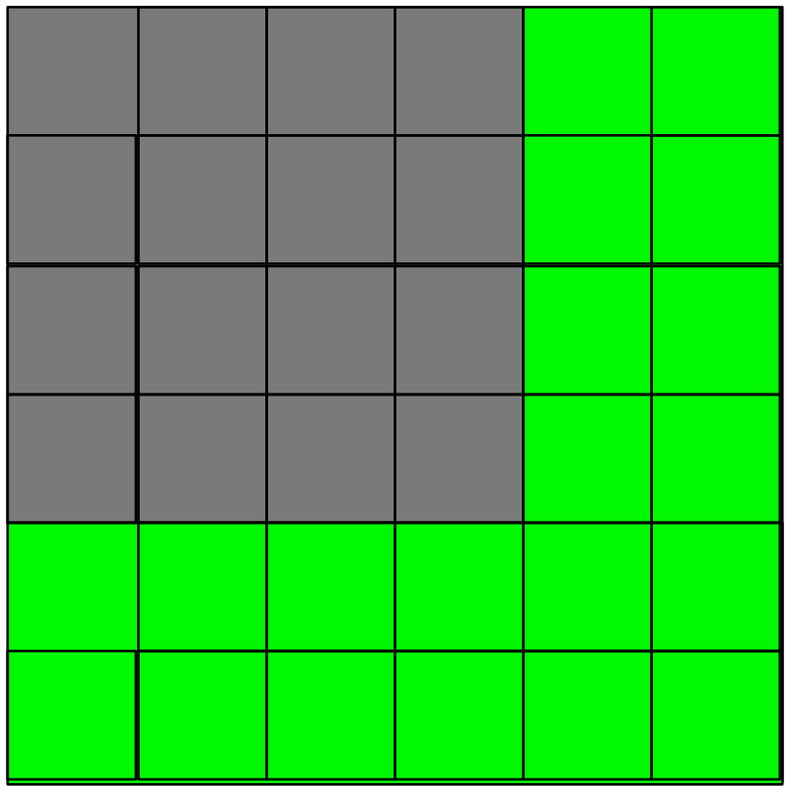


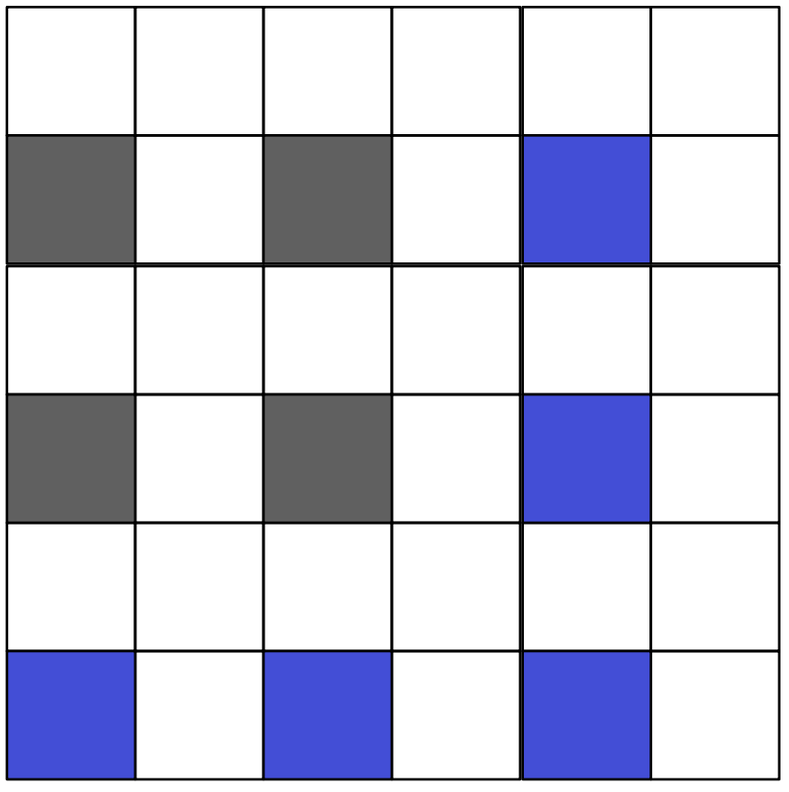


Red-Green interpolation

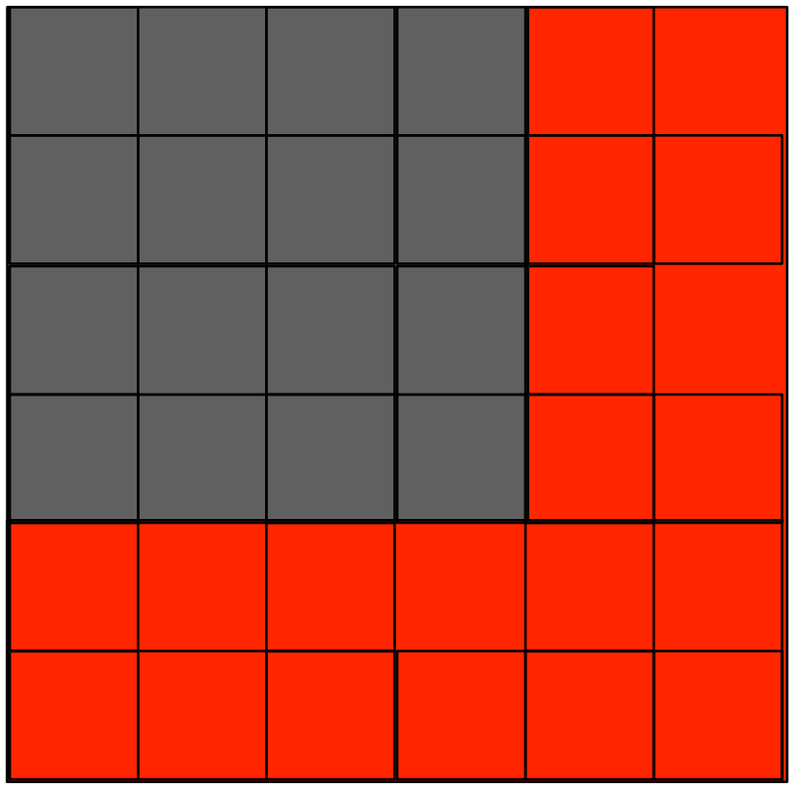
- Easy!

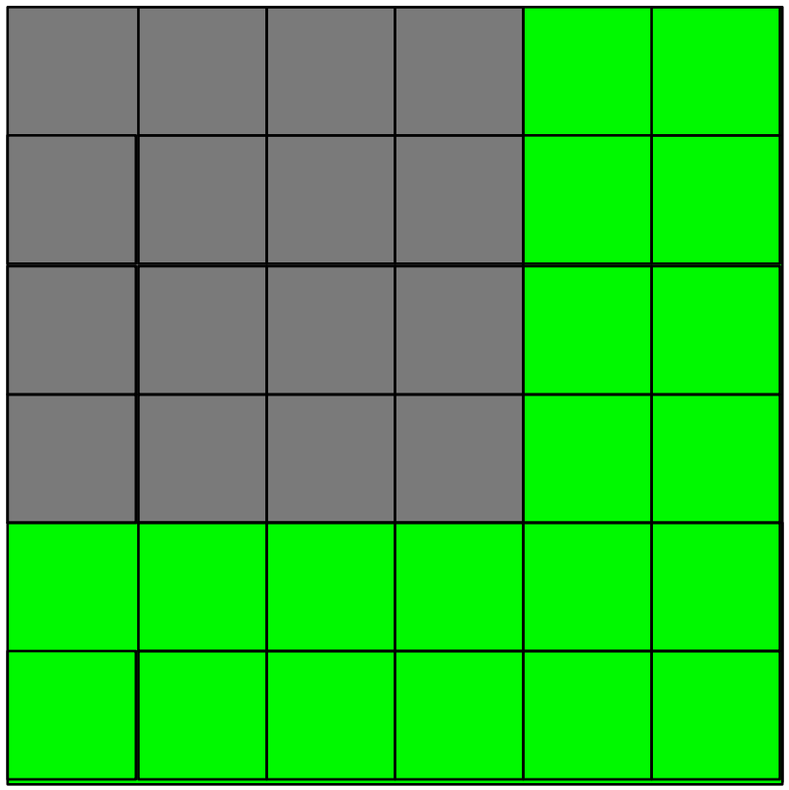


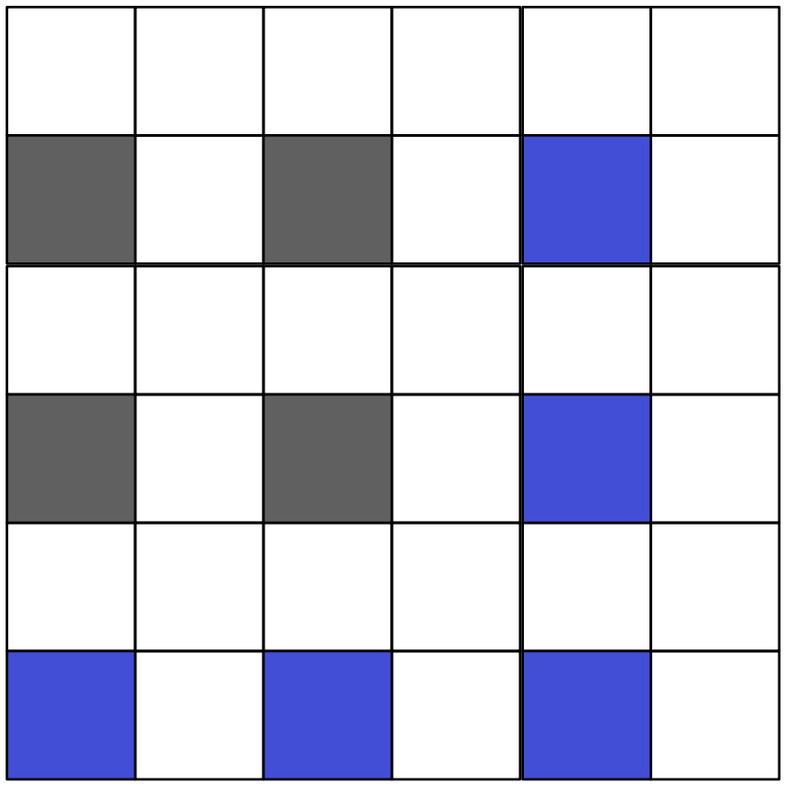




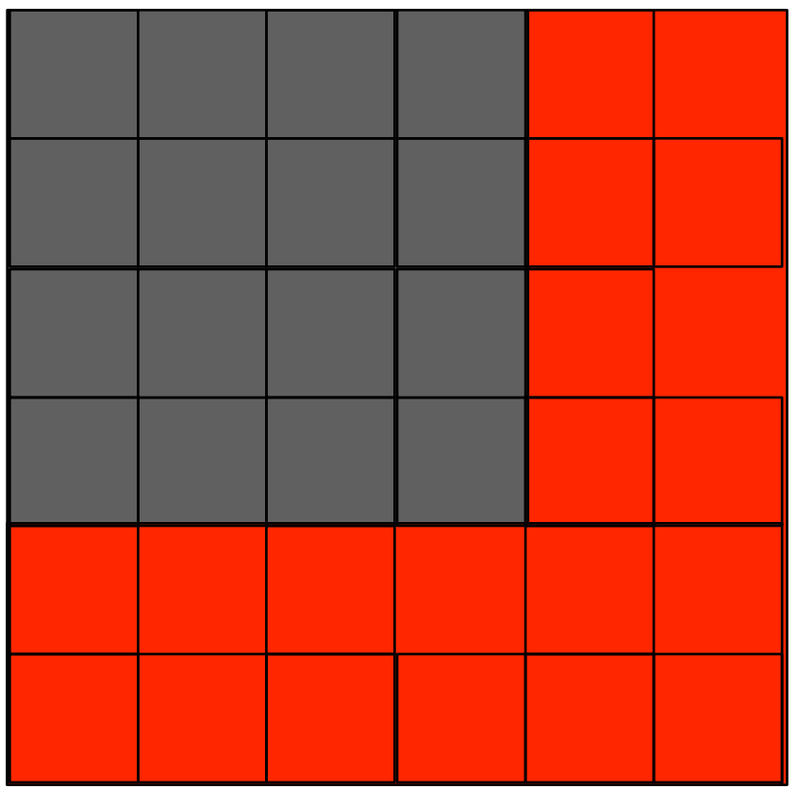
Add back green

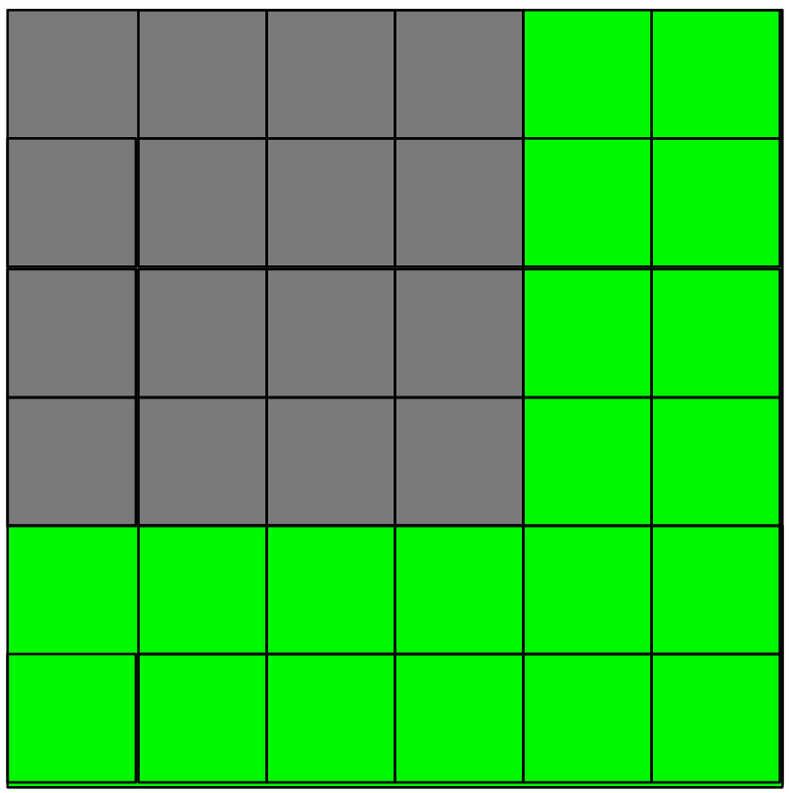


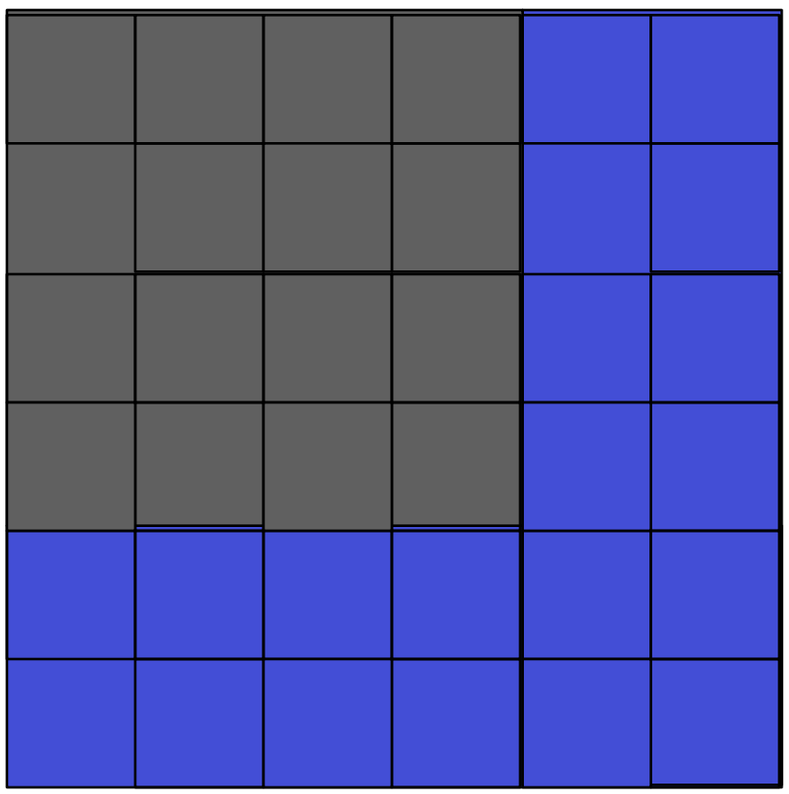




Same for blue







Fully naive



Edge-based green, naive red blue



Green-based blue and red



Still not 100% perfect

- But will be good enough for pset 4



Reference

- What we do essentially follows
  https://patents.google.com/patent/US5382976A/en
  Inventor Robert H. Hibbard (Kodak)

Questions?

Alternative

- Interpolate ratio

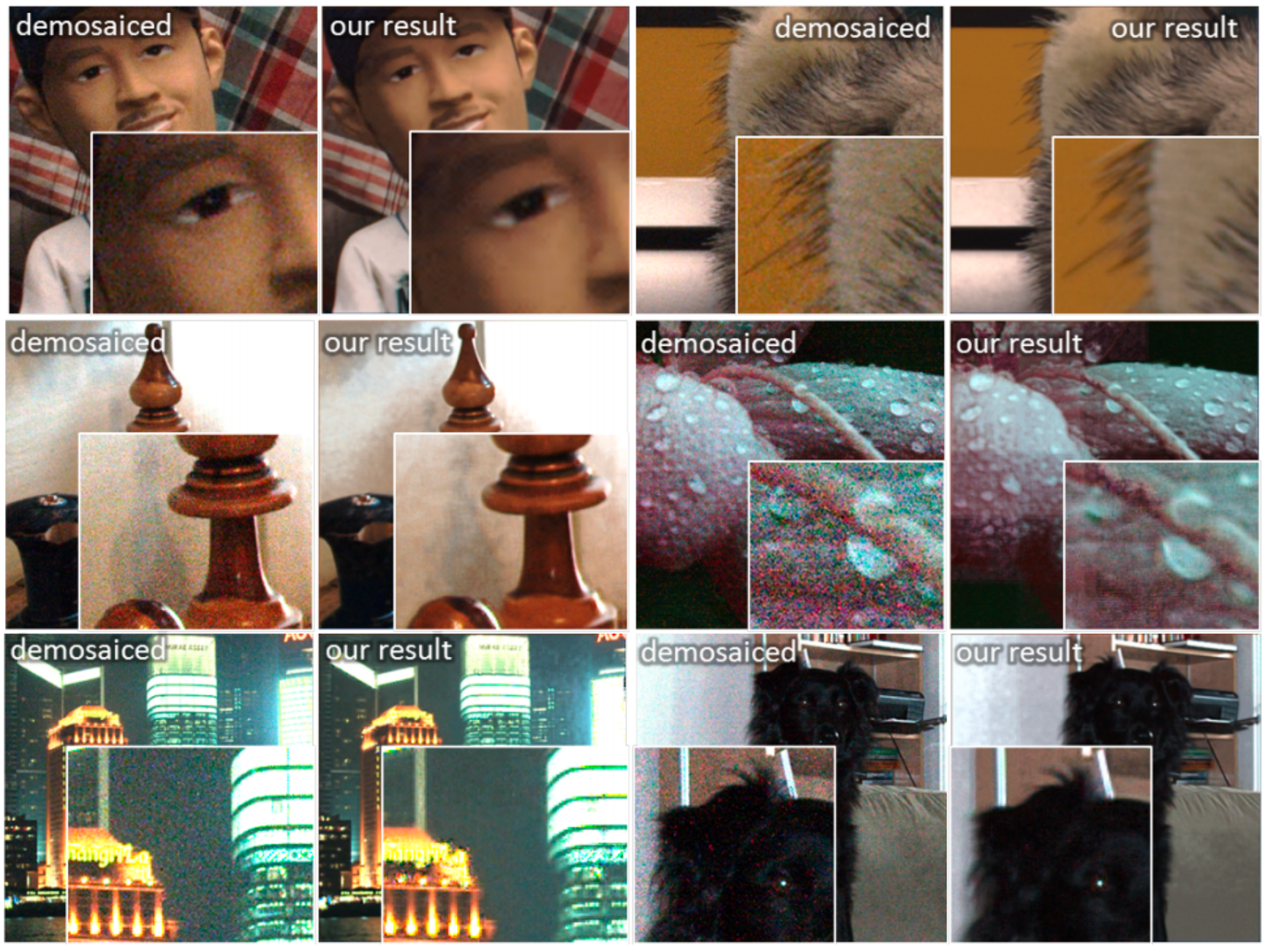
Challenges

Edge cases

- http://www.luminous-landscape.com/contents/DNG-Recover-Edges.shtml
- http://www.luminous-landscape.com/forum/index.php?topic=51328.0
-

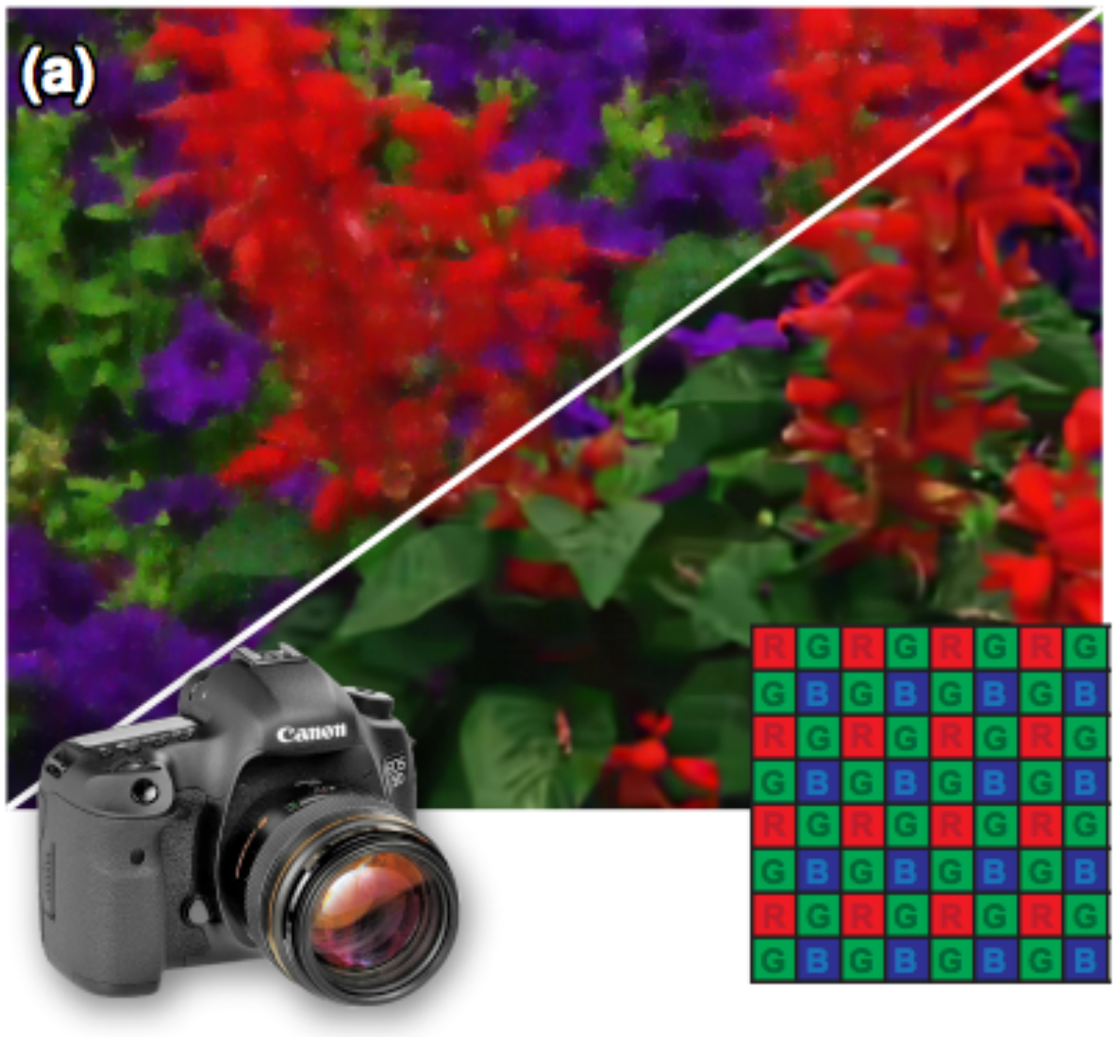
Denoising & Demosaicking

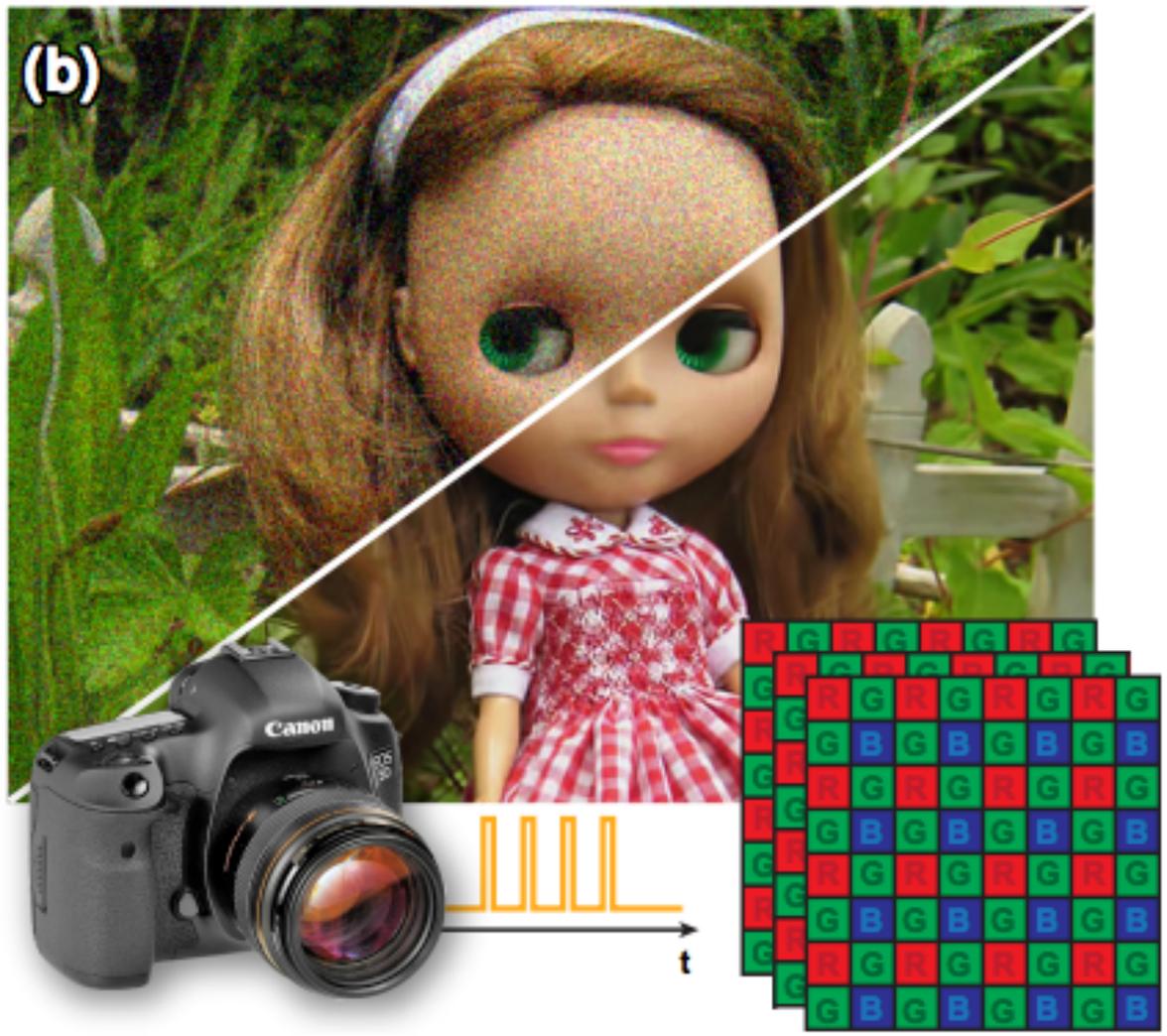
- http://research.microsoft.com/en-us/UM/people/yasumat/papers/lowlight_CVPR11.pdf



Demosaick+denoise+…

- https://research.nvidia.com/publication/flexisp-flexible-camera-image-processing-framework

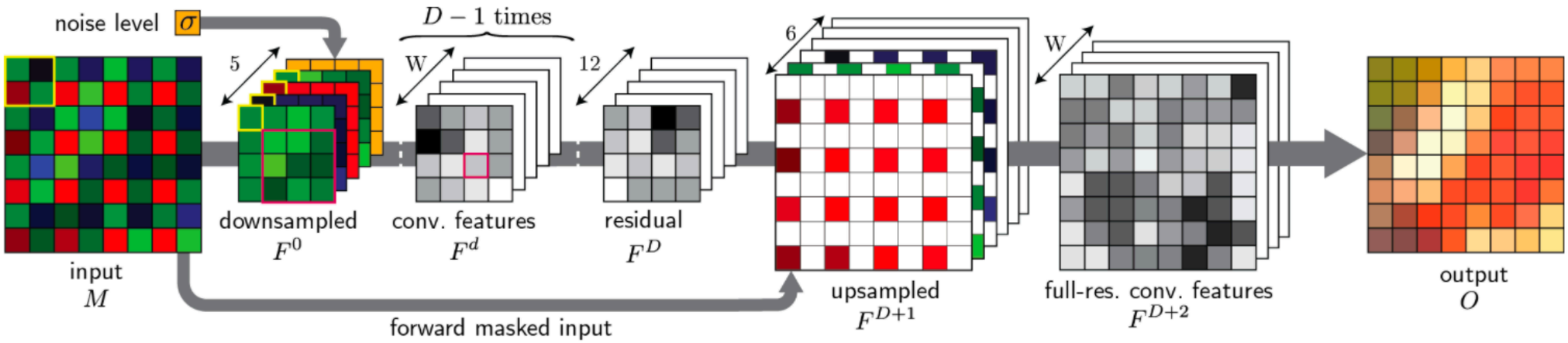




Deep Joint Demosaicking and Denoising

Siggraph Asia 2016

Michaël Gharbi — MIT CSAIL
Gaurav Chaurasia — MIT CSAIL
Sylvain Paris — Adobe
Frédo Durand — MIT CSAIL



- https://groups.csail.mit.edu/graphics/demosaicnet/
- Now in Adobe Camera Raw/Photoshop/Lightroom

Adobe Camera Raw: Enhance Details



Adobe Camera Raw "Enhance Details" Feature

https://diglloyd.com/blog/2019/20190319_1150-Adobe-EnhanceDetails-commentary.html

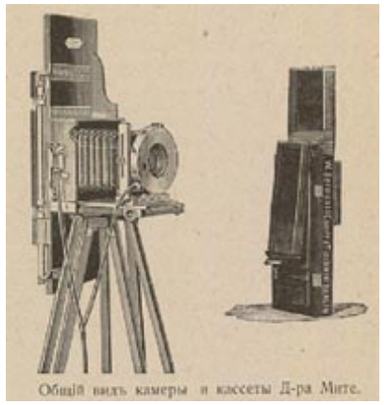
Other Color Acquisition

Color sampling

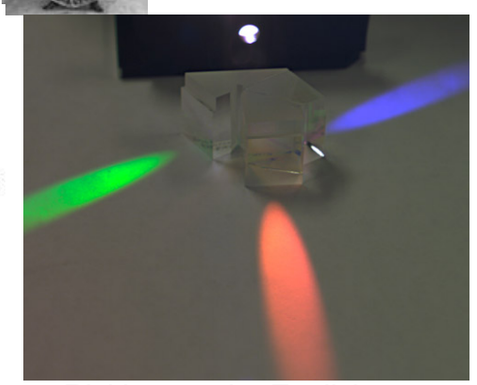
- Problem: a photosite can record only one number
- We need 3 numbers for color
- What can we do?

What are some approaches to sensing color images?

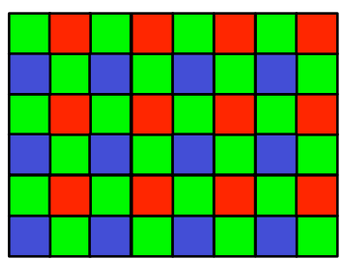
- Scan 3 times (temporal multiplexing)
- Use 3 detectors (3-ccd camera)
- Use offset color sample (spatial multiplexing)
- Multiplex in depth (Tripack film, Foveon)
- Interferences (Lipmann)



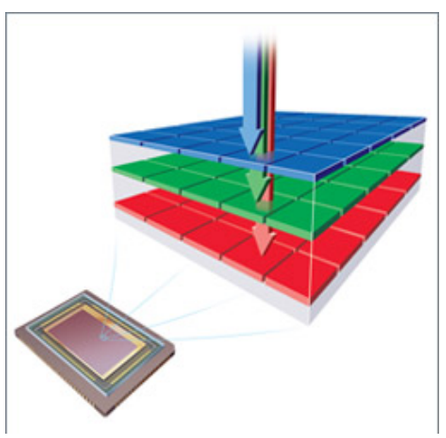




Dicklyon at the English Wikipedia project.

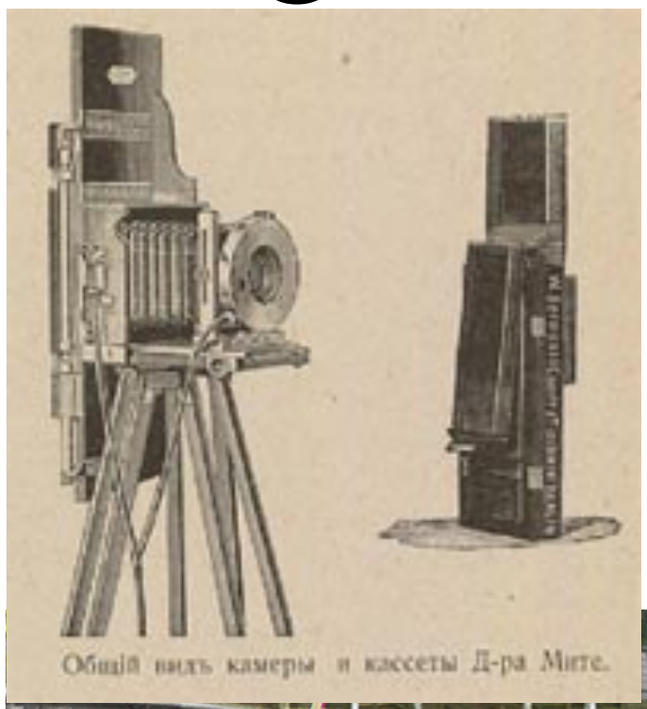






Temporal multiplexing

- Examples:
  - Drum scanners
  - Flat-bed scanners
  - Maxwell,
    Russian photographs from 1900's
- Pros:
  - 3 real values per pixel
  - Can use a single sensor
- Cons
  - Only for static scenes, slow

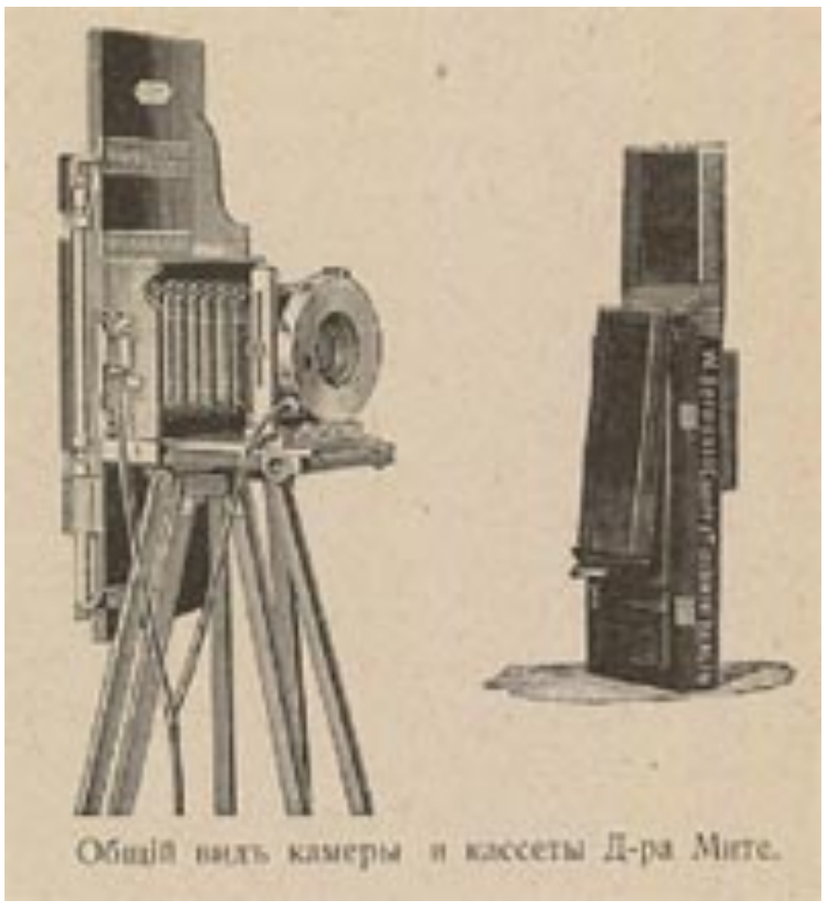






Prokudin-Gorskii

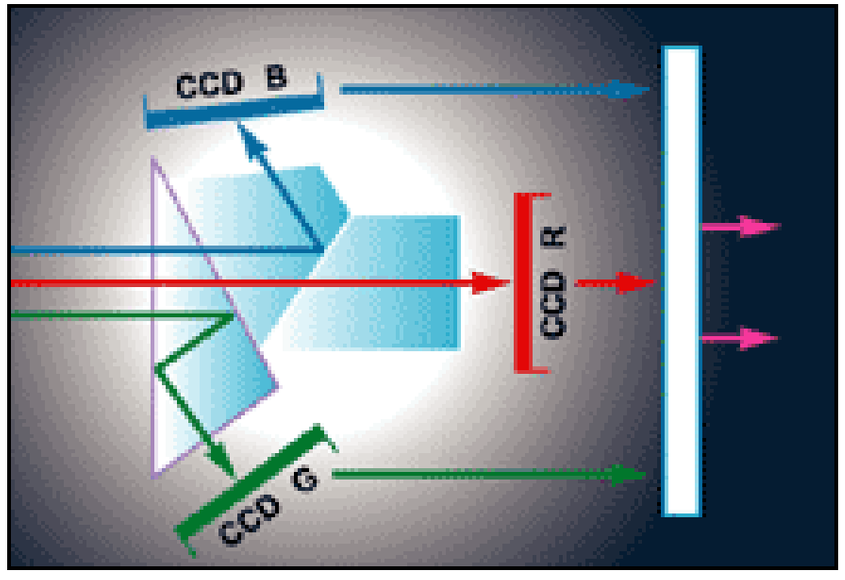
- Early 1900s
- http://en.wikipedia.org/wiki/Prokudin-Gorskii
- Pset 4 for 6.865



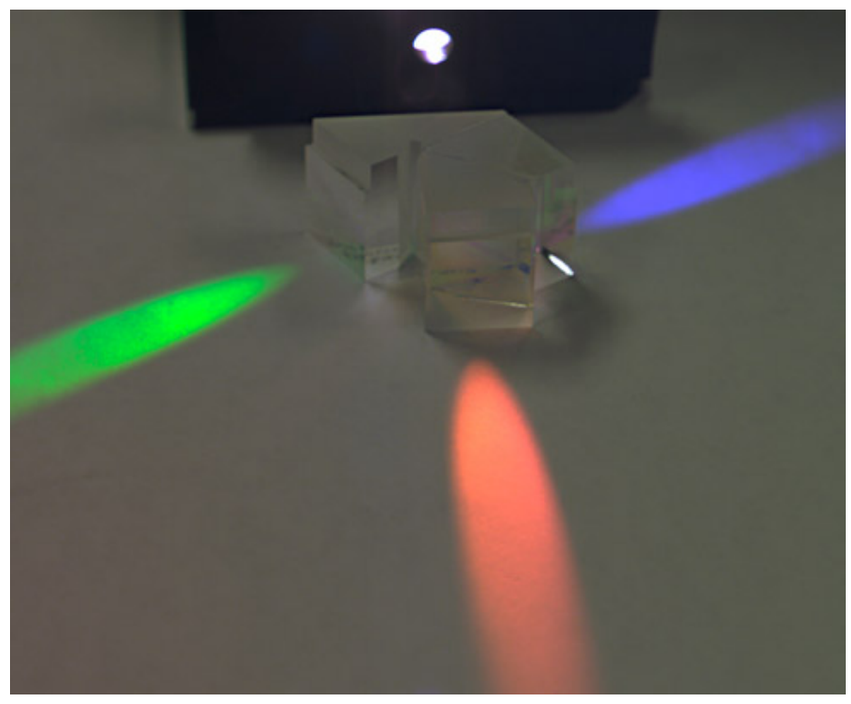




3-chip



- High-end 3-ccd video cameras
- Use separation prisms
  - prisms that split wavelengths
- Pros
  - 3 real values per pixel
  - Little photon loss
- Cons
  - costly (needs 3 sensors)
  - space

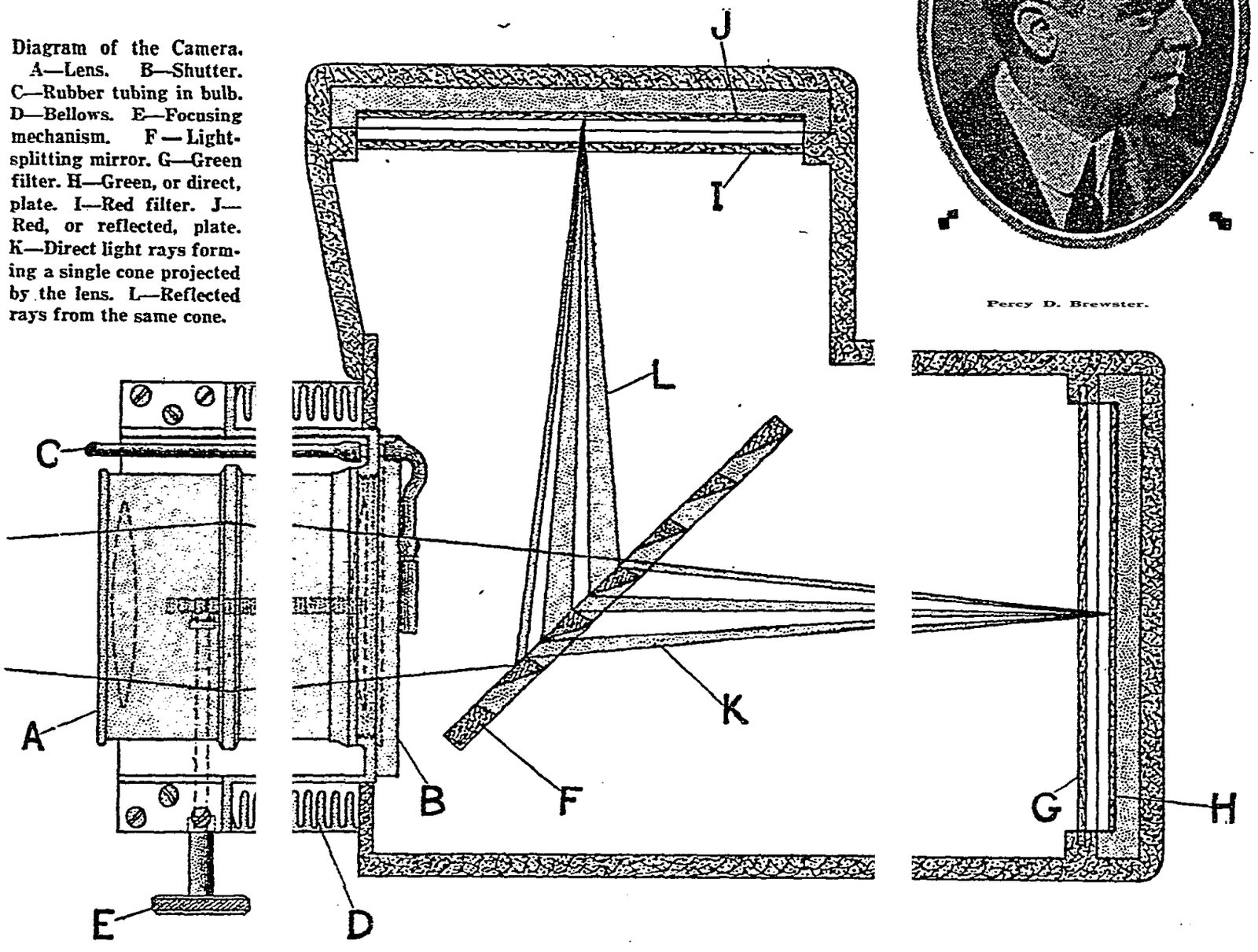


Dicklyon at the English Wikipedia project.

Brewster's version

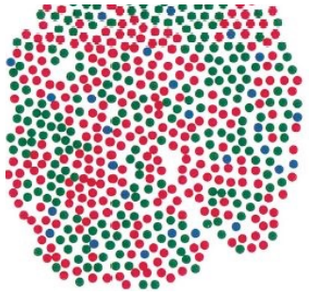
- Swiss cheese mirror

Diagram of the Camera. A—Lens. B—Shutter. C—Rubber tubing in bulb. D—Bellows. E—Focusing mechanism. F—Light-splitting mirror. G—Green filter. H—Green, or direct, plate. I—Red filter. J—Red, or reflected, plate. K—Direct light rays forming a single cone projected by the lens. L—Reflected rays from the same cone.

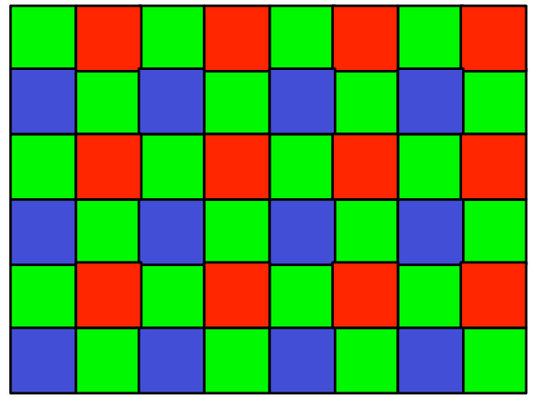


Percy D. Brewster.

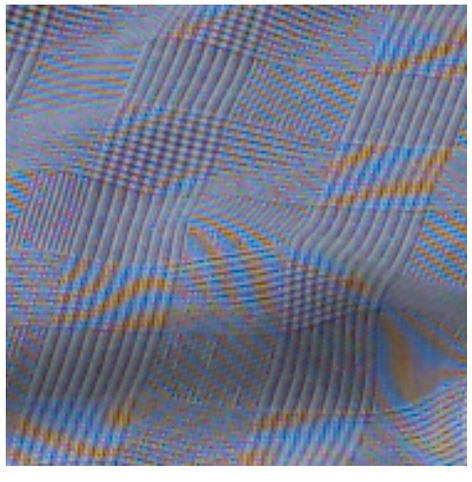
Spatial multiplexing





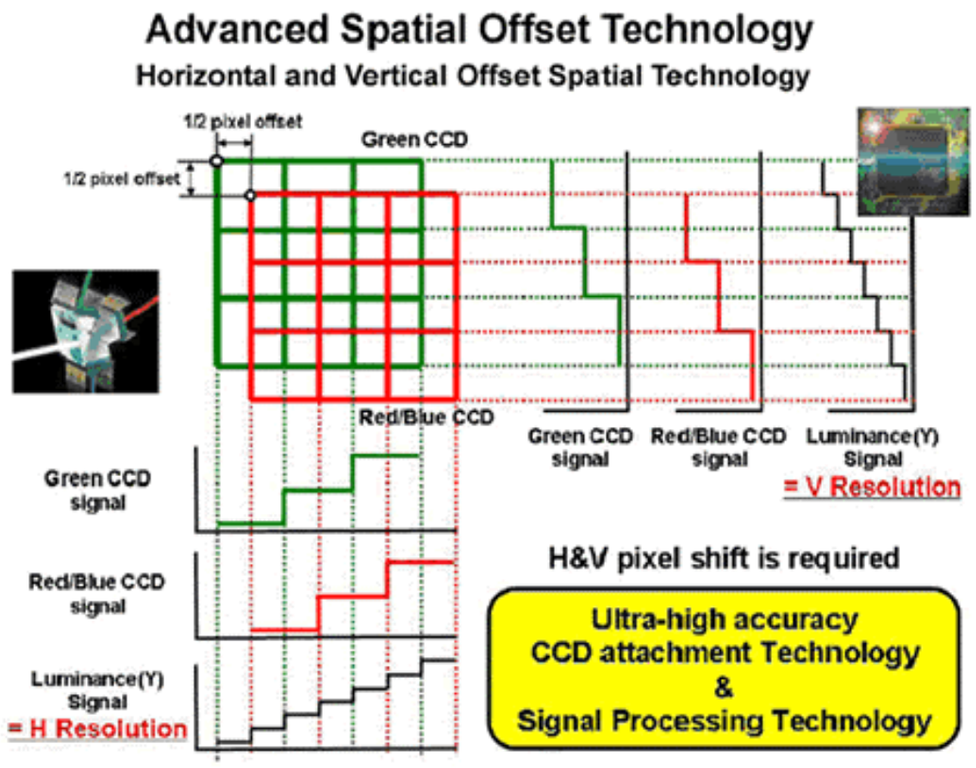


- Human eye (cone mosaic)
- Older color film (Autochrome)
- Bayer mosaic or CFA (color filter array)
- Most still cameras, most cheap camcorder, some high-end video cameras (e.g. RED)
- Pros
  - single sensor
  - well mastered technology, high resolution
- Cons
  - needs interpolation, color jaggies
  - requires antialiasing filter (reduces sharpness)
  - loss of light



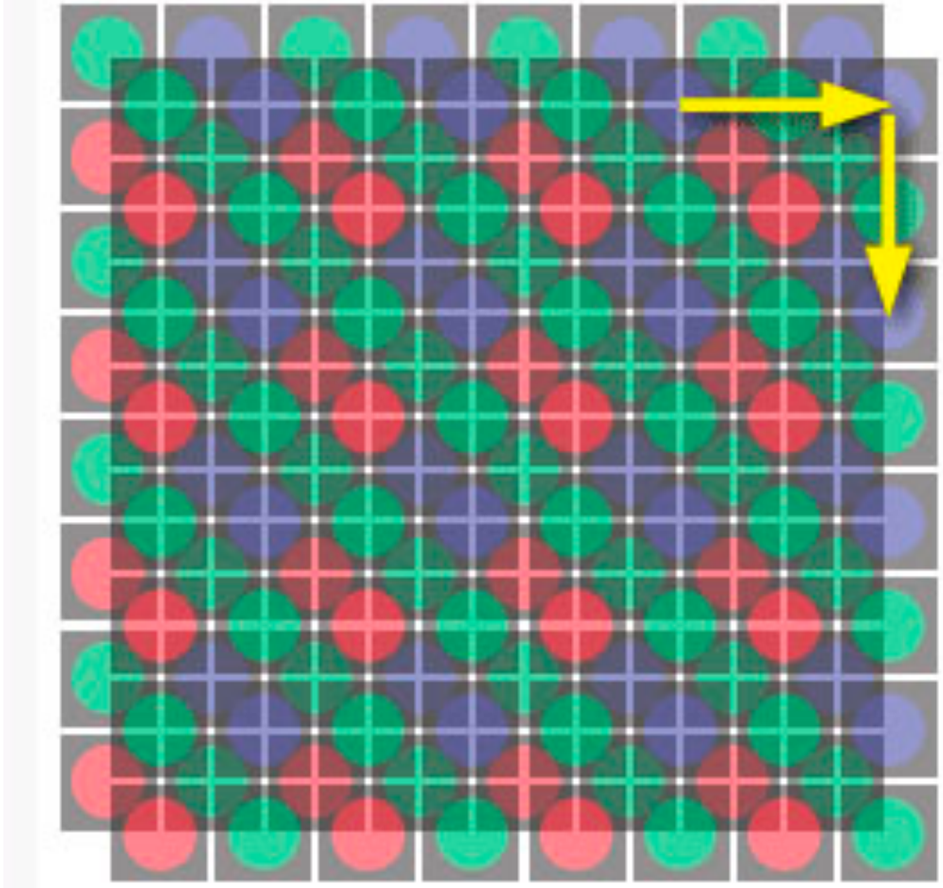
Combination: pixel shift

- 3-ccd with prisms + spatial multiplexing
- The 3 ccds are shifted by 1/2 pixel to provided resolution increase
  - usually selectable (not shifted for lower-res, shifted to get HD)
  - Often horizontal only



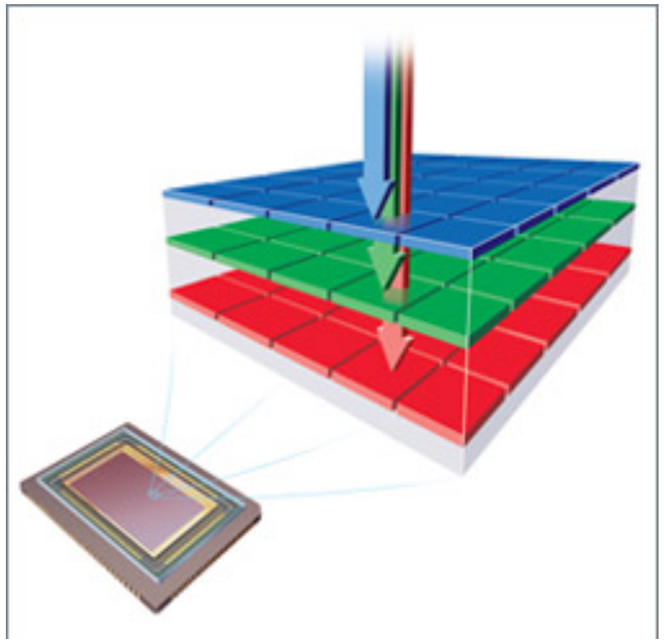
From Panasonic

- http://www.petapixel.com/2011/05/26/hasselblad-h4d-200ms-shoots-200mp-photos-with-a-50mp-sensor/

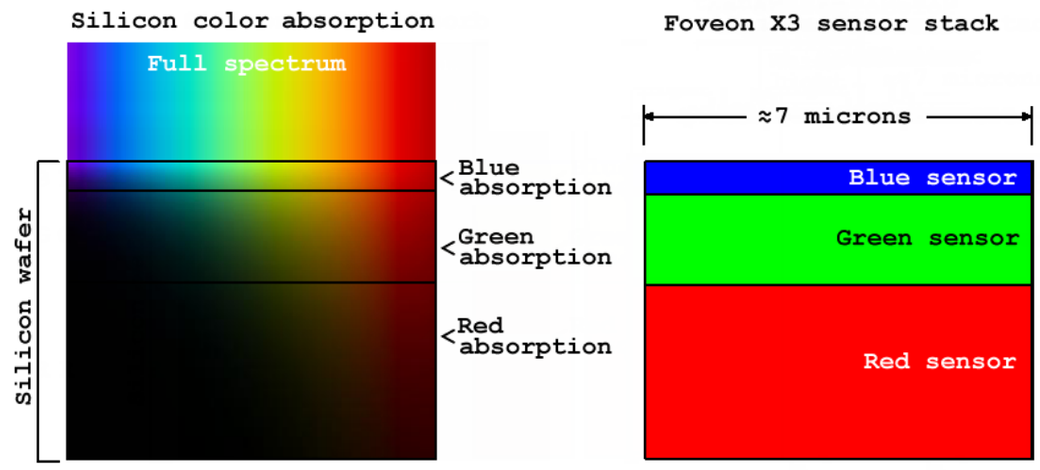




Depth multiplexing (Foveon X3 sensor)

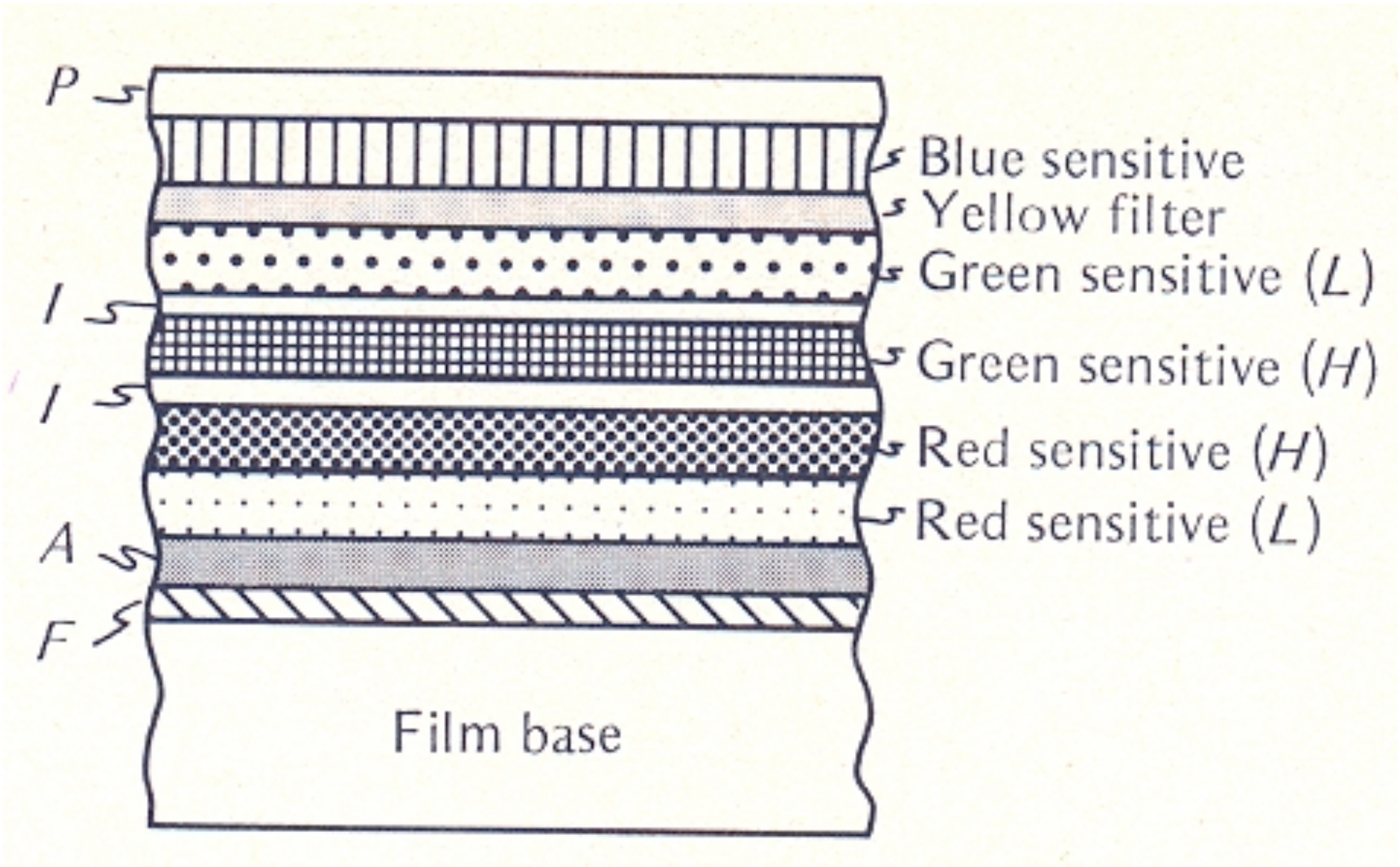


- Leverage difference in absorption per wavelength
- Pros
  - 3 real numbers per pixel
  - Less light loss
- Cons
  - Requires more color processing (3 numbers must be multiplied by matrix to get RGB)
  - Tends to be noisier (because color processing and because shallow blue layer)



Depth multiplexing

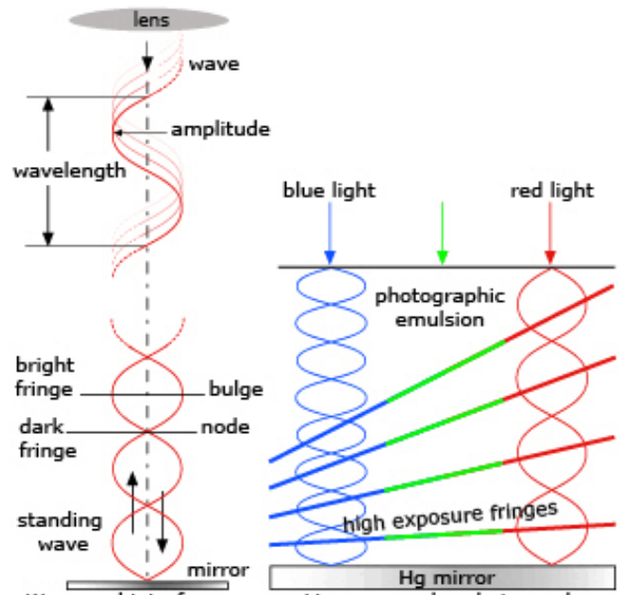
- Good old color film (tripack)



Interferences (Lippmann process)



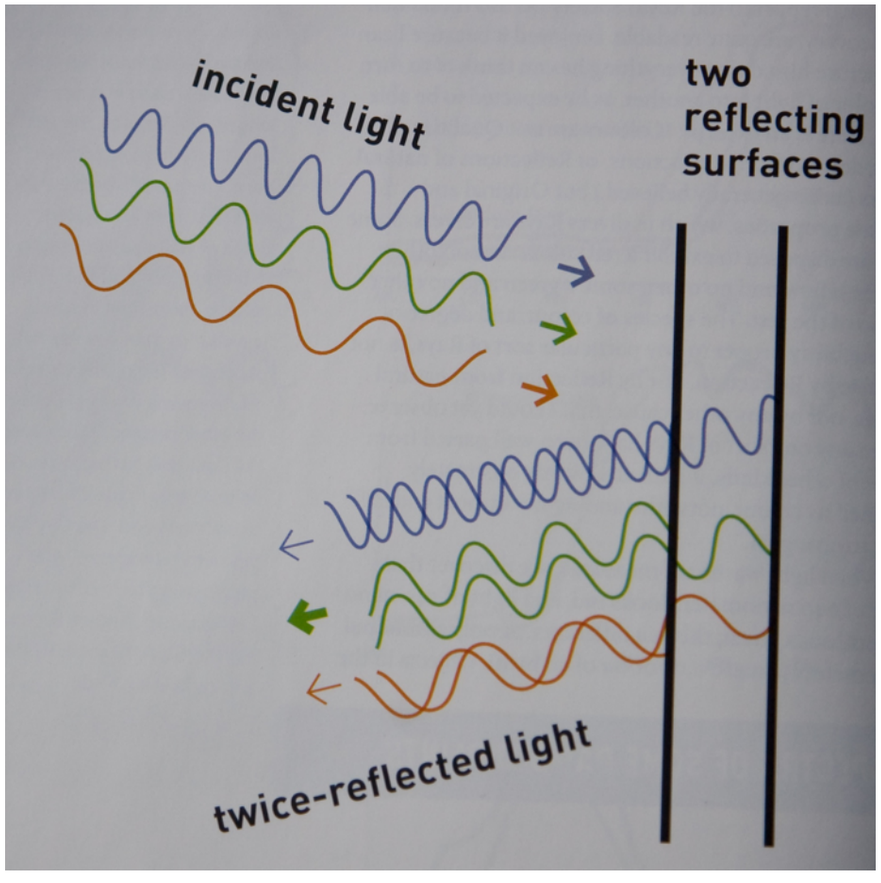
- Metal mirror to create interferences
  - ancestor of holography
  - similar to colors in thin oil film



Wave and interference Lippmann color photography

http://nobelprize.org/nobel_prizes/physics/articles/biedermann/index.html

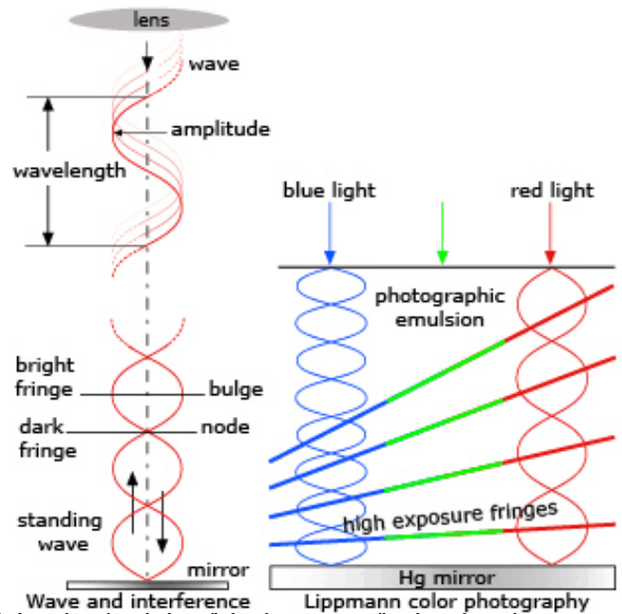




Interferences (Lippmann process)



- Metal mirror to create interferences
  - ancestor of holography
  - similar to colors in thin oil film
- Pros
  - Full spectrum!!!!!
  - Gets you the Nobel if you invent it ;-)
- Cons
  - Needs high-resolution sensor/film
  - limited field of view for display



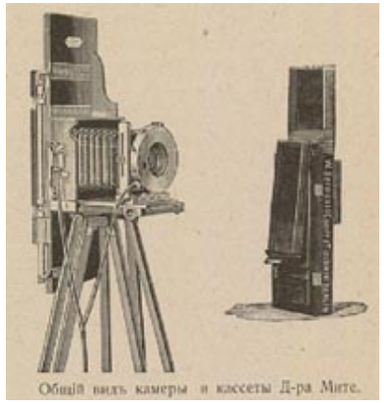
http://nobelprize.org/nobel_prizes/physics/articles/biedermann/index.html



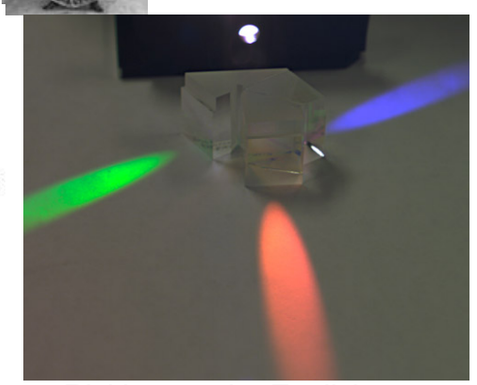
'Saint-Maxime", 1891-1899
Photographer: Gabriel Lippmann (1845-1929)

Recap & Questions?

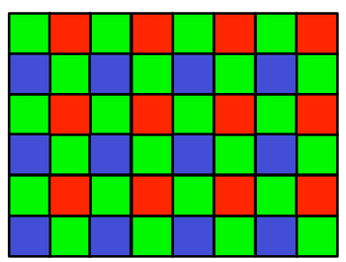
- Scan 3 times (temporal multiplexing)
- Use 3 detectors (3-ccd camera)
- Use offset color sample (spatial multiplexing)
- Multiplex in depth (Tripack film, Foveon)
- Interferences (Lipmann)



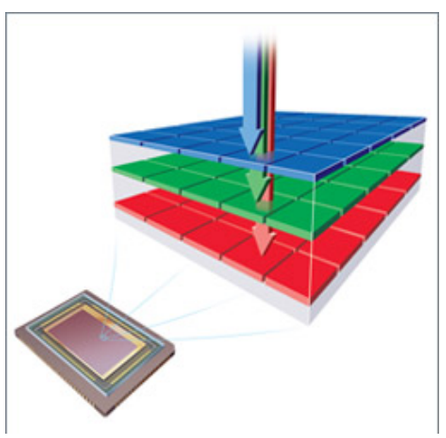




Dicklyon at the English Wikipedia project.







Links

- What we do essentially follows https://patents.google.com/patent/US5382976A/en , Inventor Robert H. Hibbard (Kodak)

- http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.141.634&rep=rep1&type=pdf
  - http://www.unc.edu/~rjean/demosaicing/demosaicing.pdf — NEEDS TO BE FIXED
- http://www.pages.drexel.edu/~par24/rawhistogram/40D_Demosaicing/40D_DemosaicingArtifacts.html
- http://www.guillermoluijk.com/tutorial/dcraw/index_en.htm
- http://www.cambridgeincolour.com/tutorials/RAW-file-format.htm
- http://www.cambridgeincolour.com/tutorials/camera-sensors.htm

More

- http://www.ists.dartmouth.edu/library/edf0205.pdf
- http://ieeexplore.ieee.org/iel5/79/30519/01407714.pdf?isnumber=30519&prod=JNL&arnumber=1407714&arSt=+44&ared=+54&arAuthor=Guntu rk%2C+B.K.%3B+Glotzbach%2C+J. %3B+Altunbasak%2C+Y. %3B+Schafer%2C+R.W. %3B+Mersereau%2C+R.M.