CS6640 Computational Photography

7. Digital camera processing pipeline

Camera processing pipeline

- **read image out from sensor** —see Sensors lecture
- **optional: HDR assembly** —see Homework 2
- **color balance** —see Color lecture
- **demosaic**
- **noise processing**
- **color matrix** —see Color lecture
- **tone map**

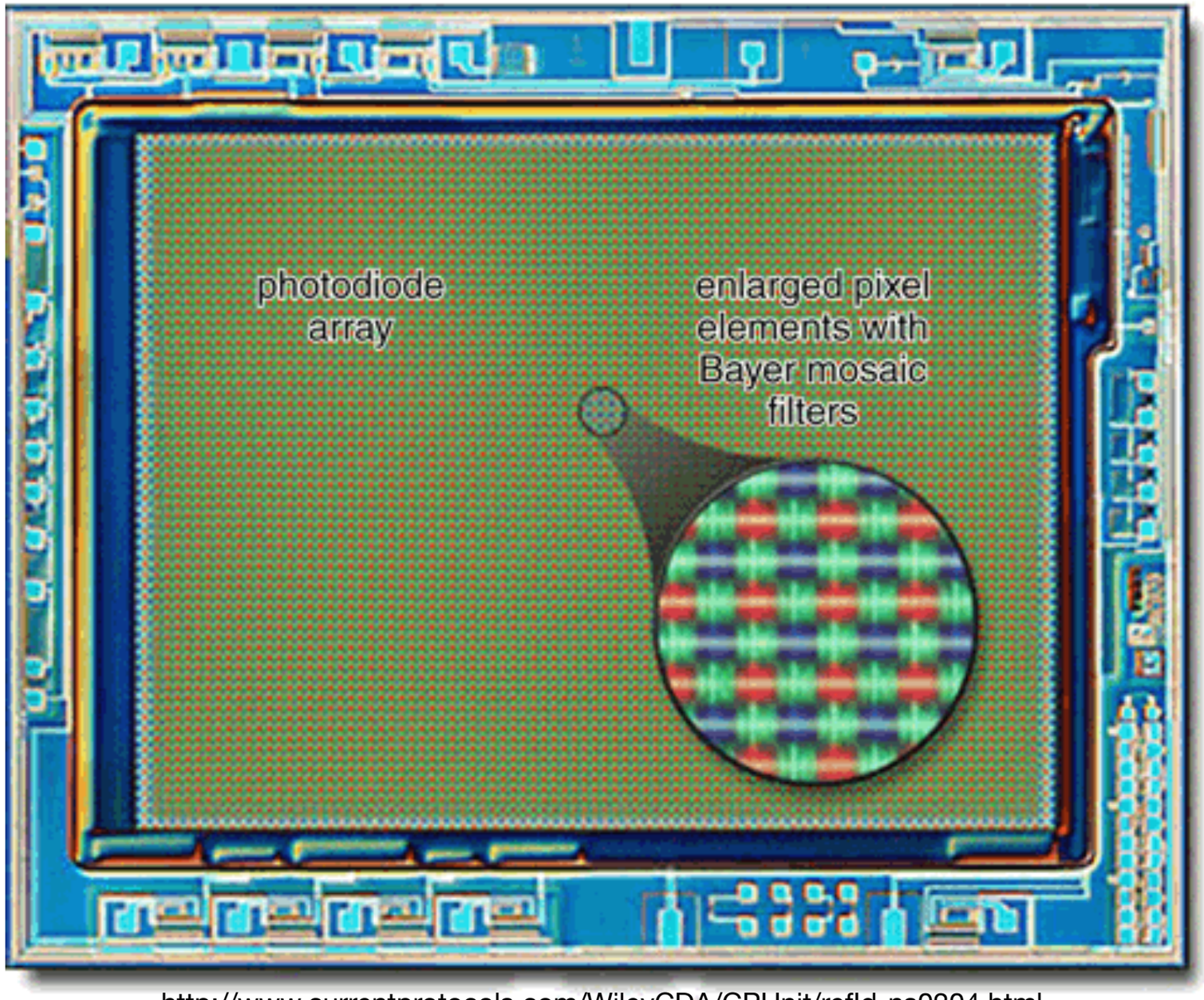
Demosaicking

- **First question: how to spell it**

  I cite “picnicking”

- **Each photosite senses only one color**

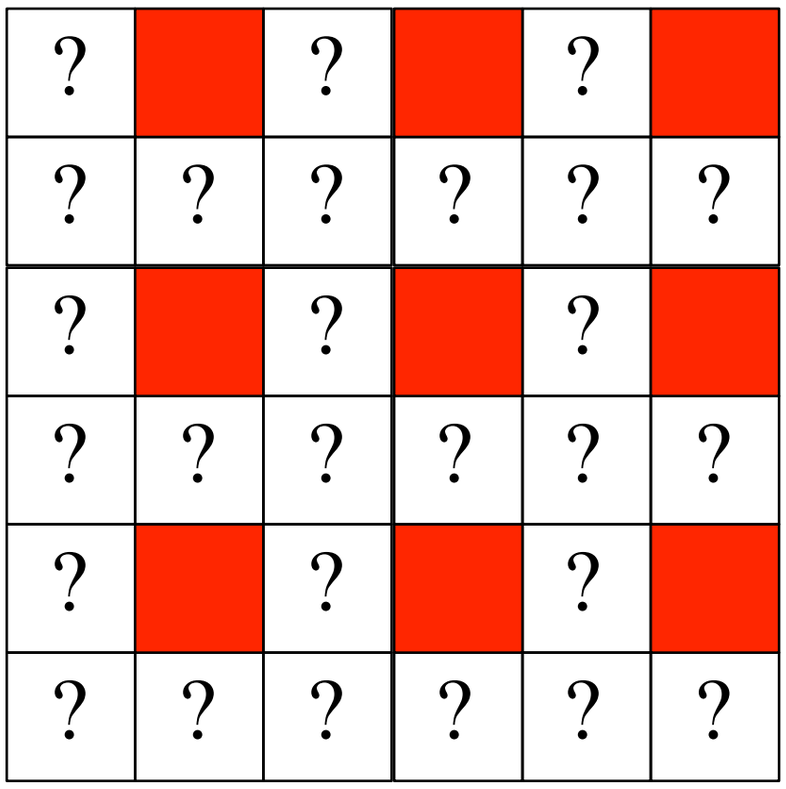
- **We need three measurements at each pixel**

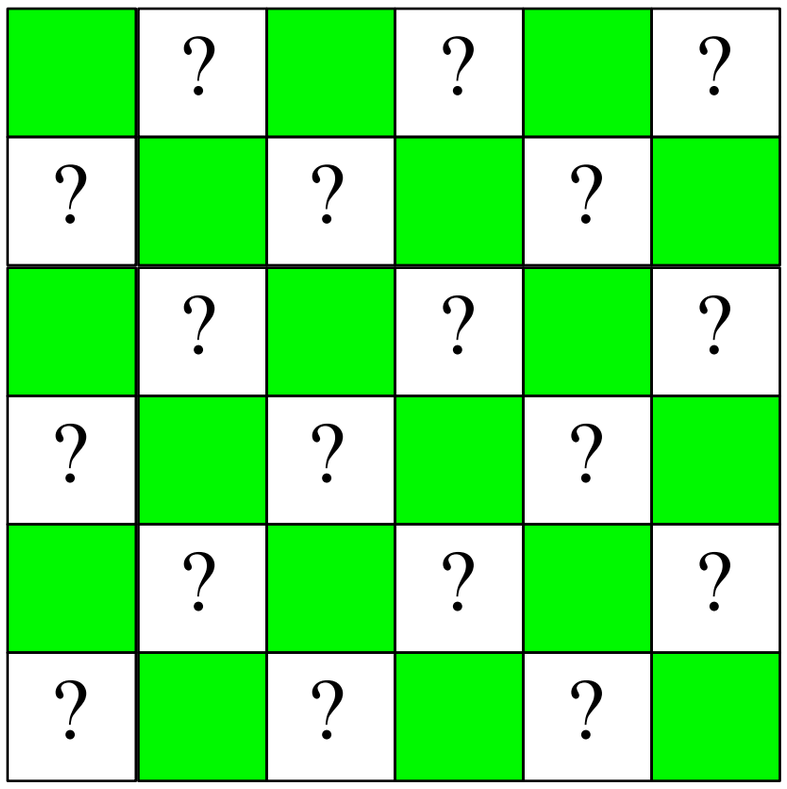


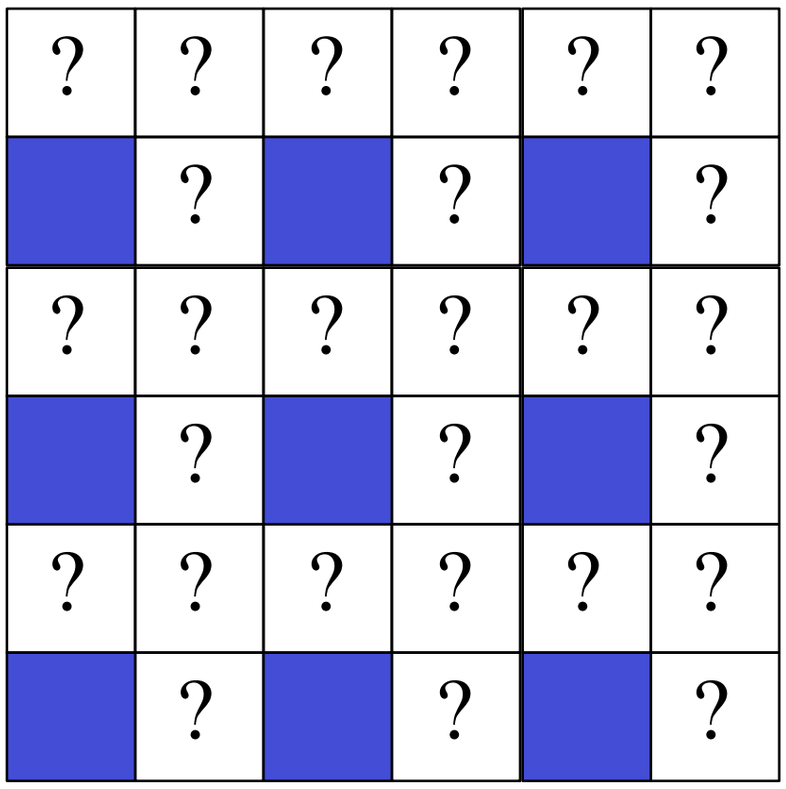
http://www.currentprotocols.com/WileyCDA/CPUnit/refId-ns0204.html

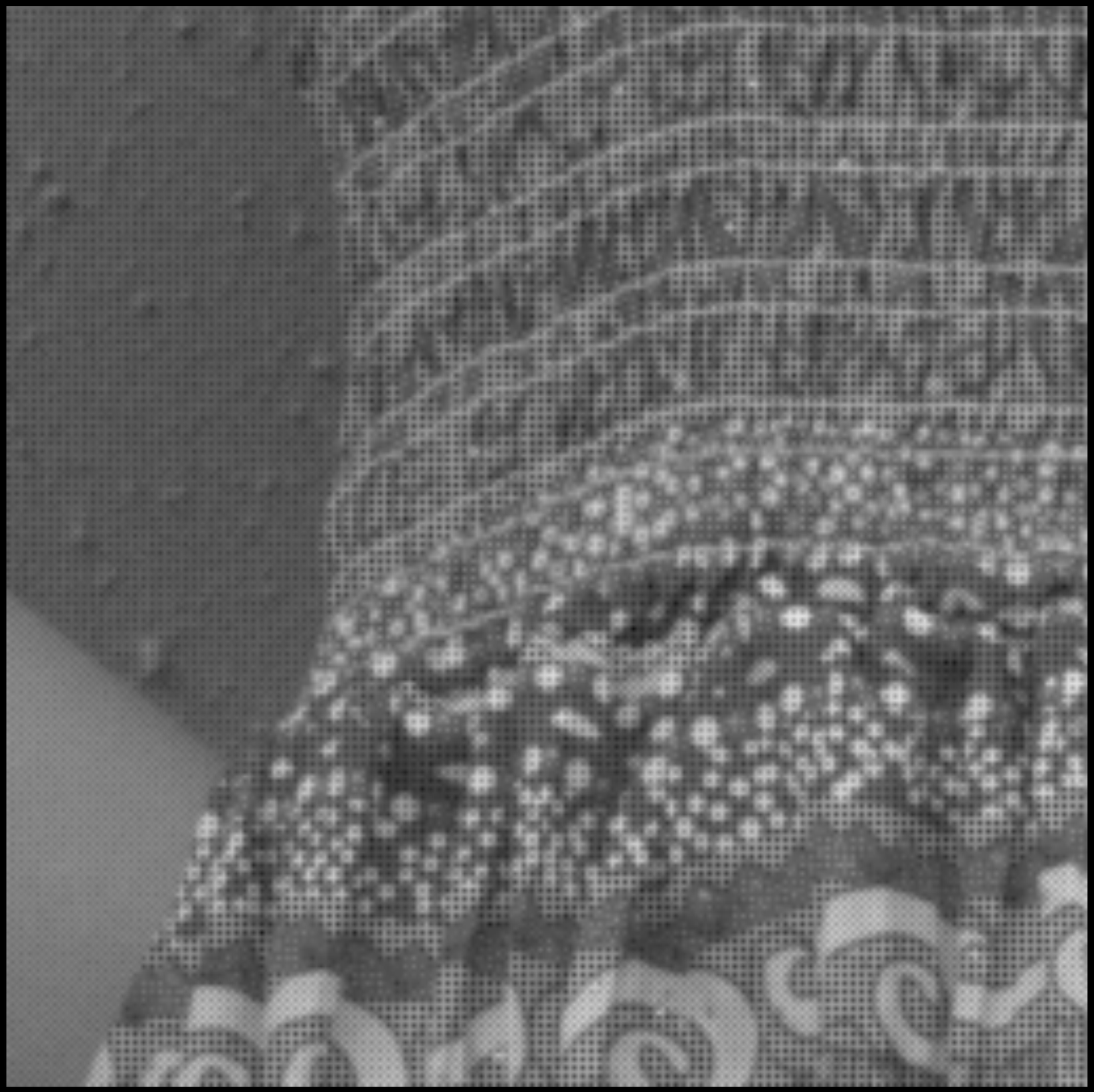
Bayer array

- **Simple solution: make a half-resolution image**
- **Want sensor-resolution image? Make up 2/3 of the data!**

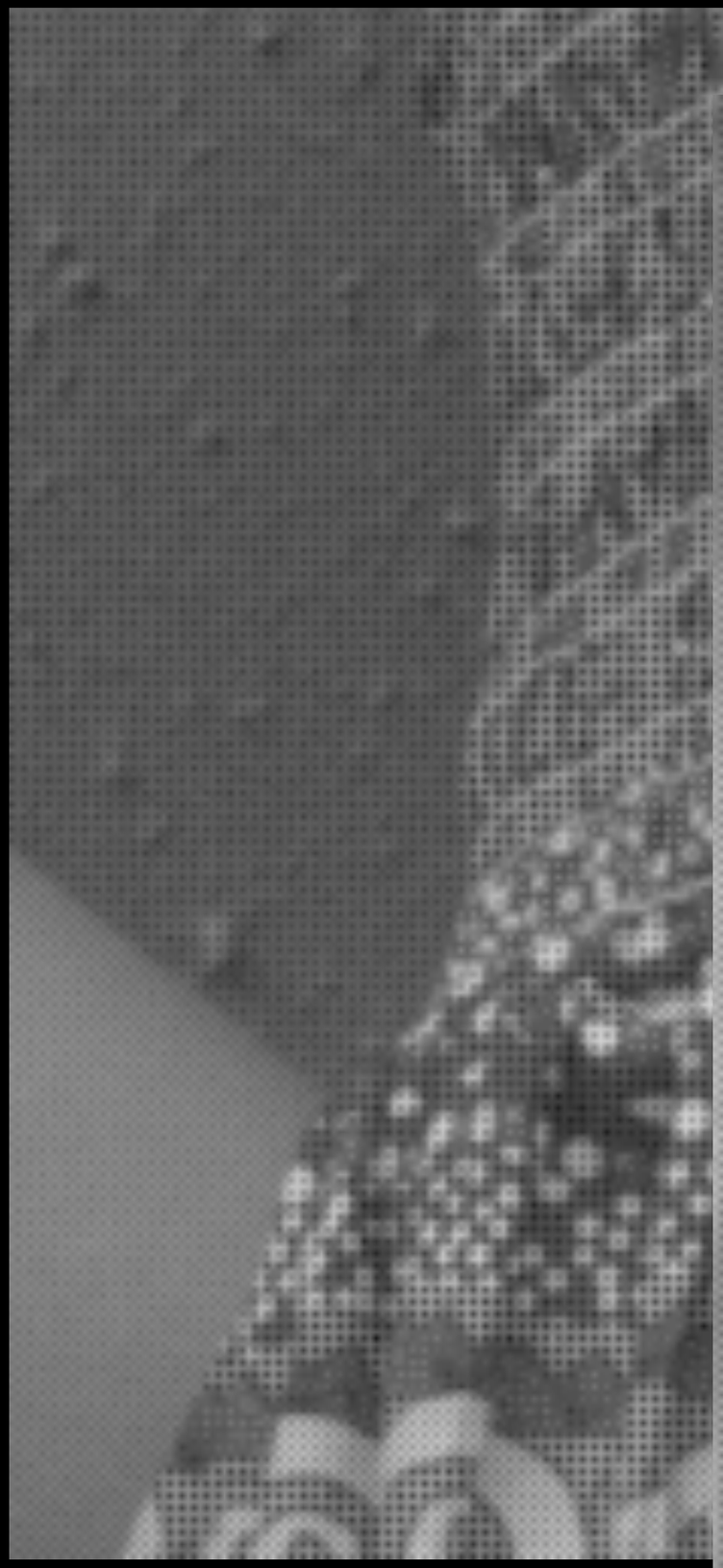








bayer



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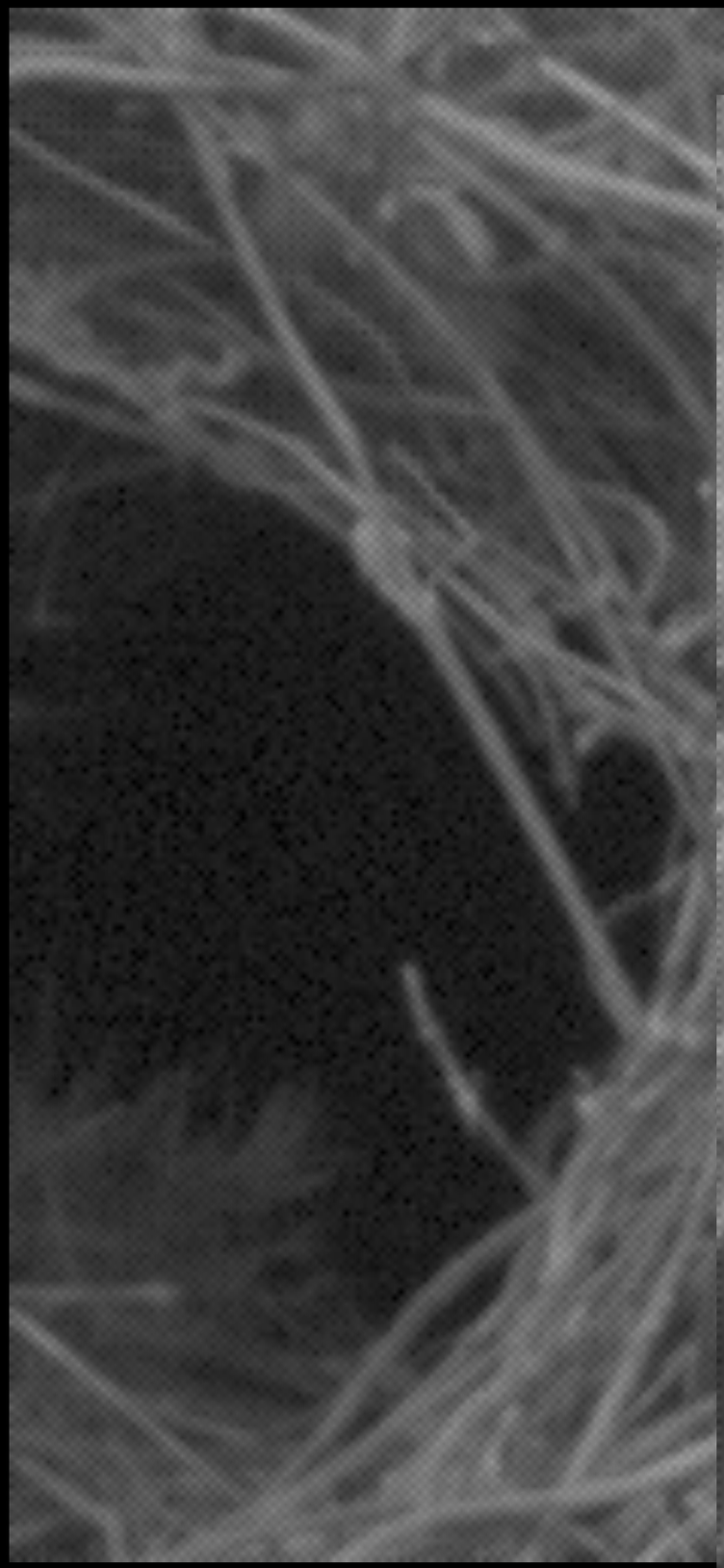
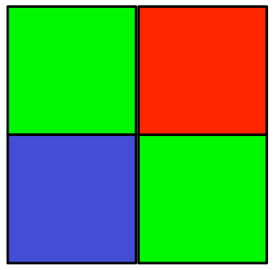


bayer

bayer

Half-resolution demosaic

- **Idea 1: treat each block of four pixels as a pixel**



Easy to code up in one line of Matlab. But what is wrong with this?

Half-resolution demosaic

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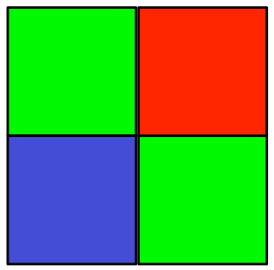

Easy to code up in one line of Matlab. But what is wrong with this?

1. throws away too much resolution

Half-resolution demosaic

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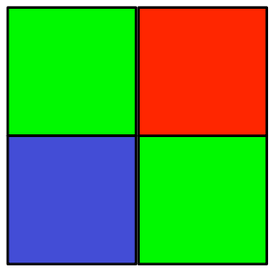
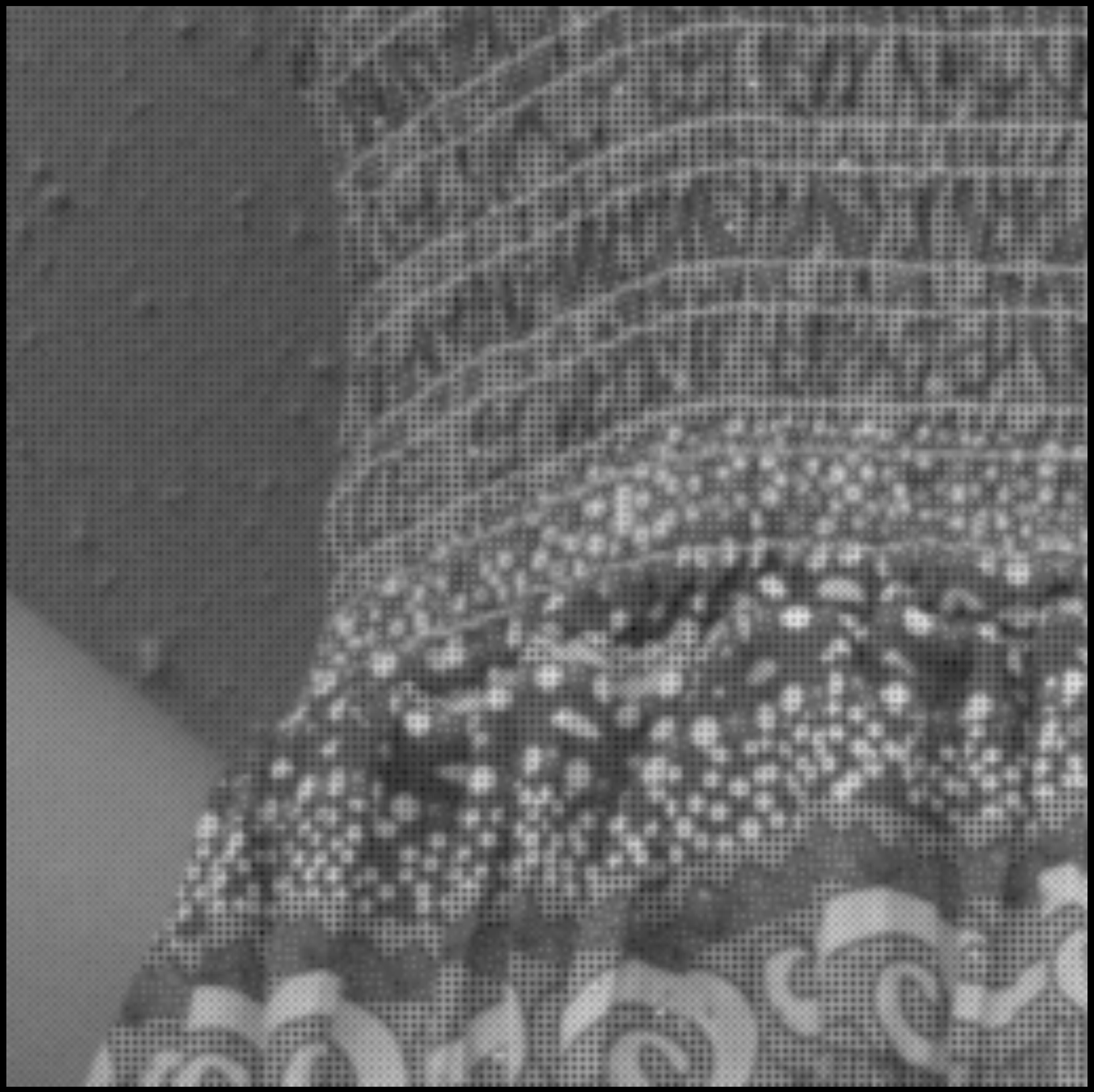


Easy to code up in one line of Matlab. But what is wrong with this?

1. throws away too much resolution
2. produces subpixel shifts in color planes!



bayer

block

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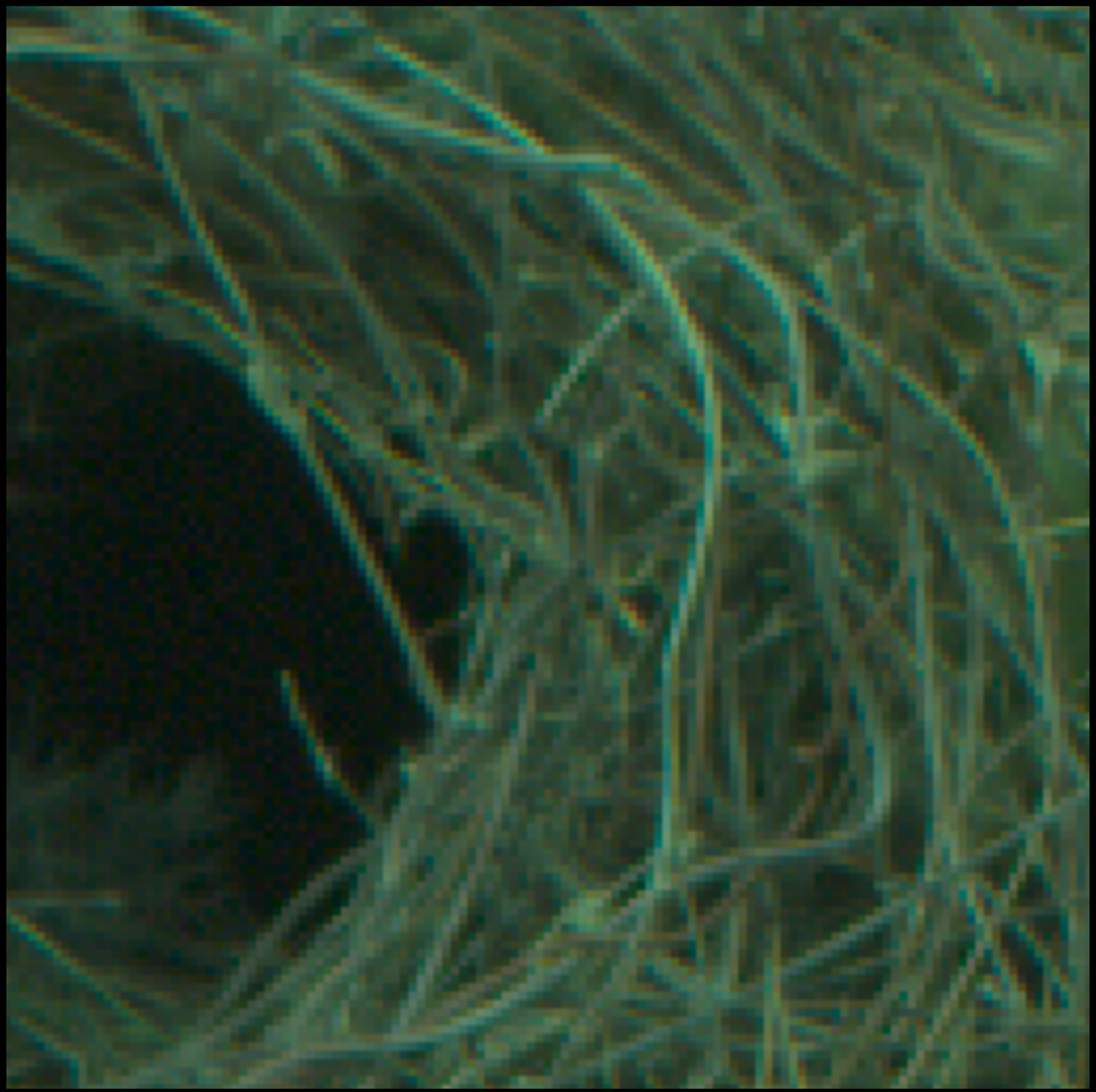

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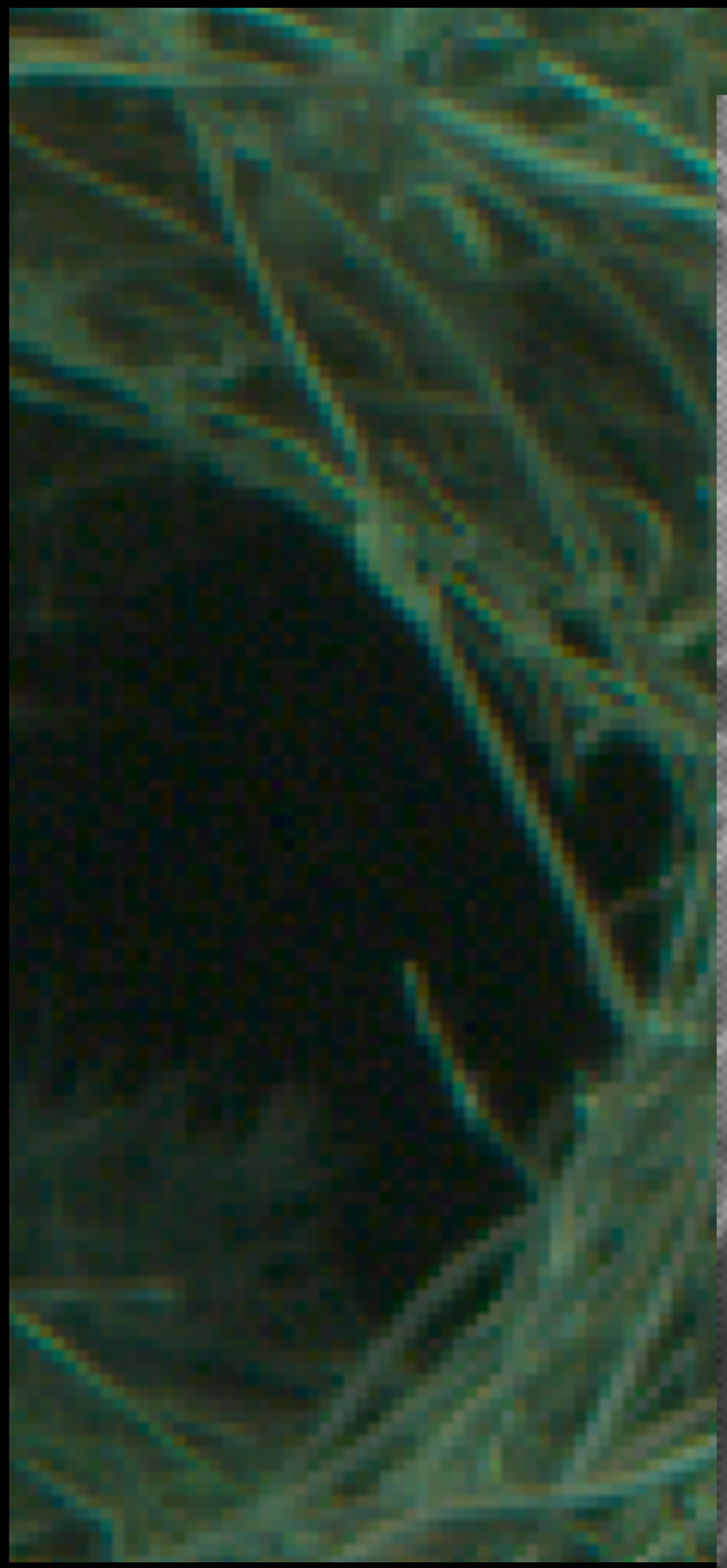

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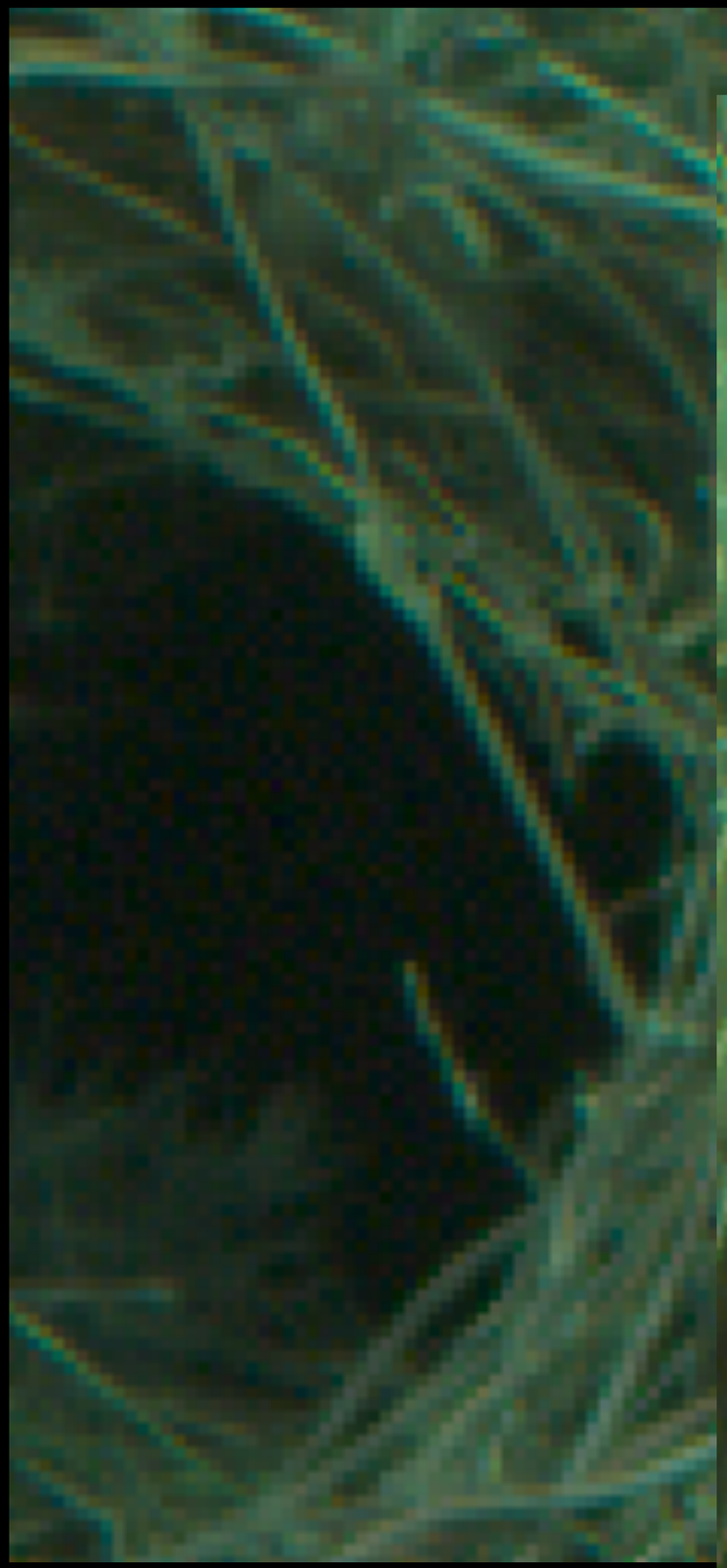

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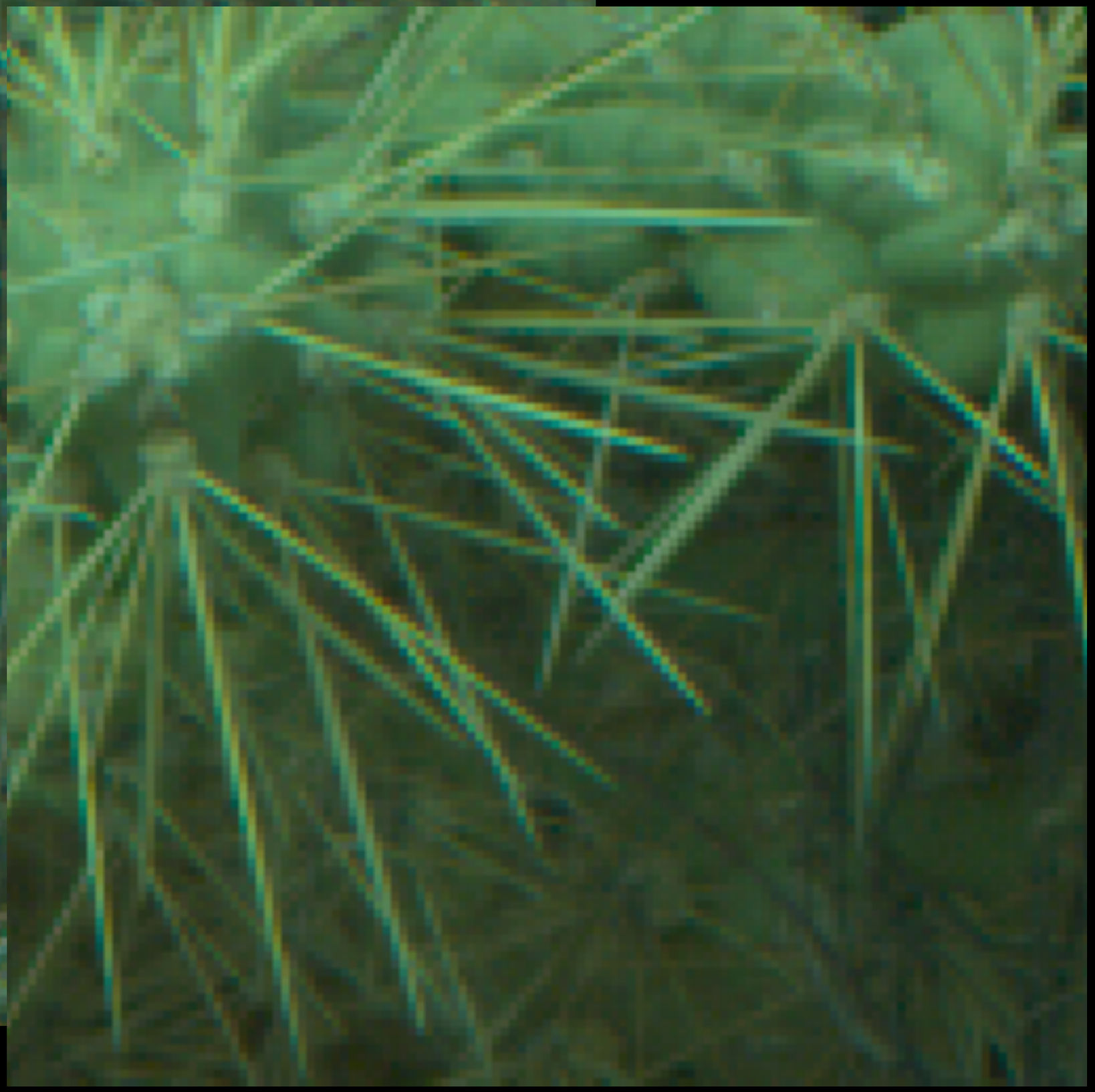
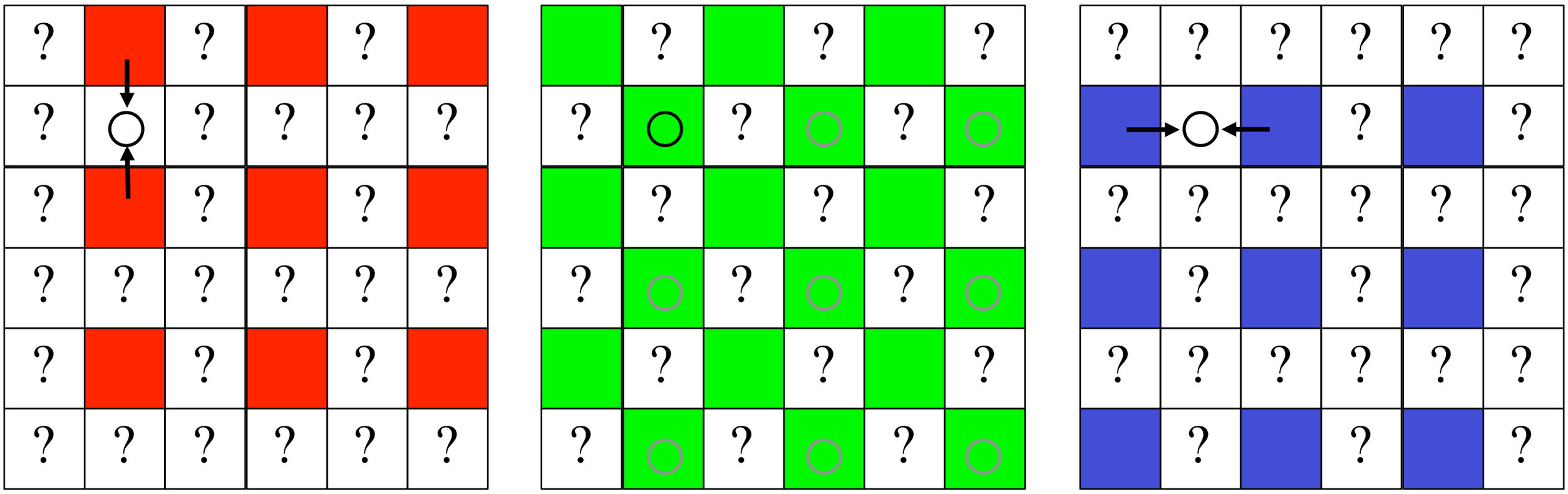


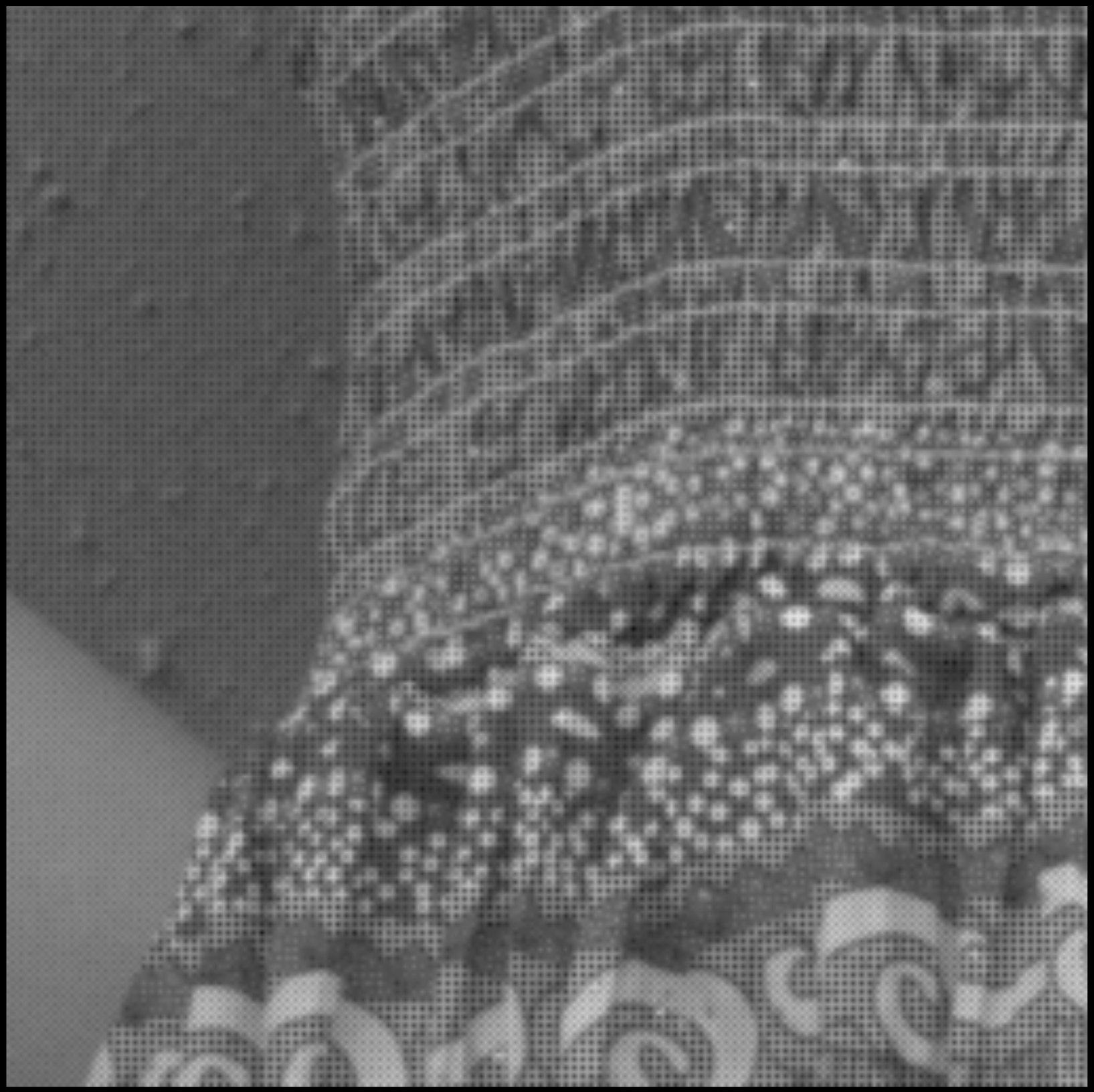
block

Centered half-resolution

- **Average pixels in groups that all have the same "center of gravity"**

  avoids major color fringing

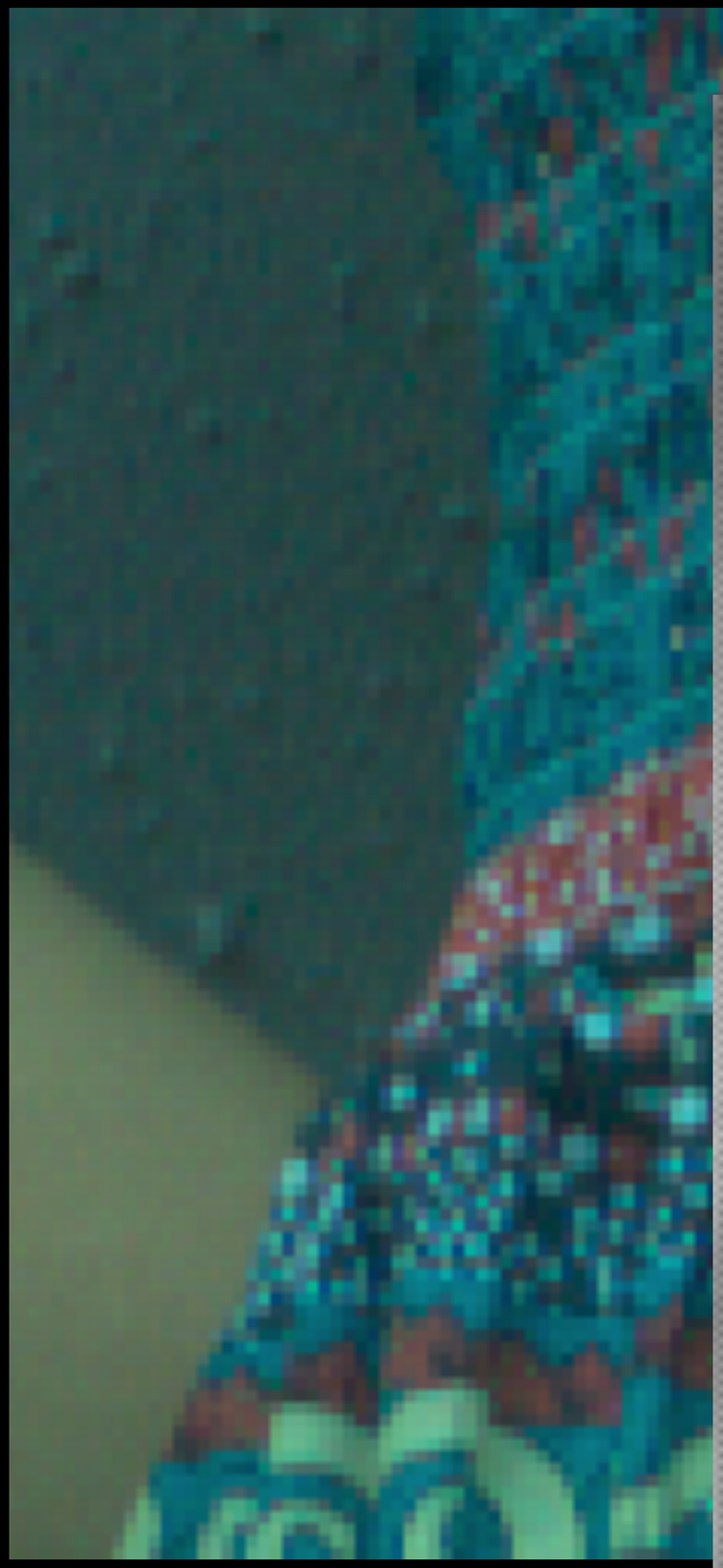




bayer

block

centered



centered

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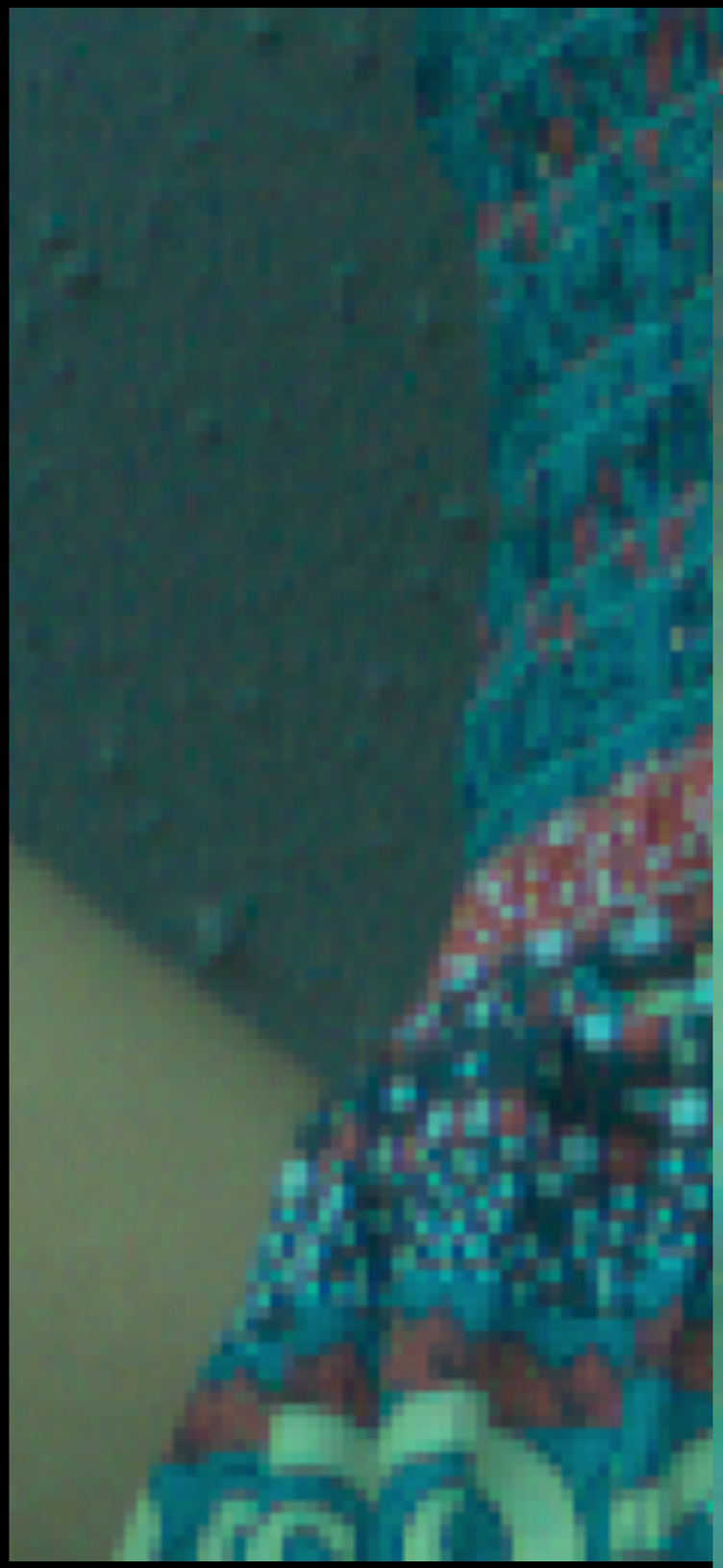

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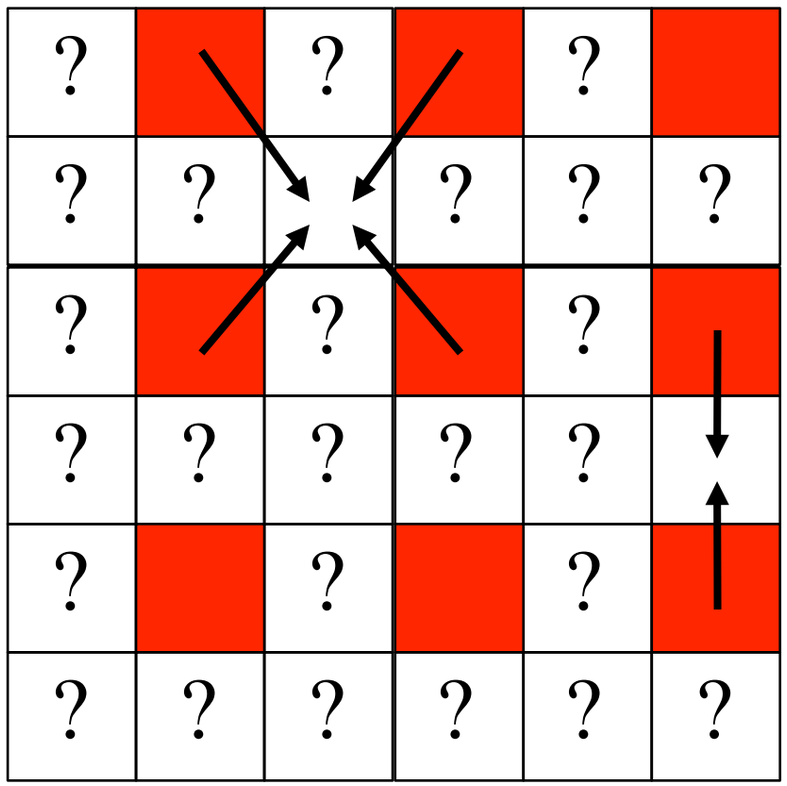
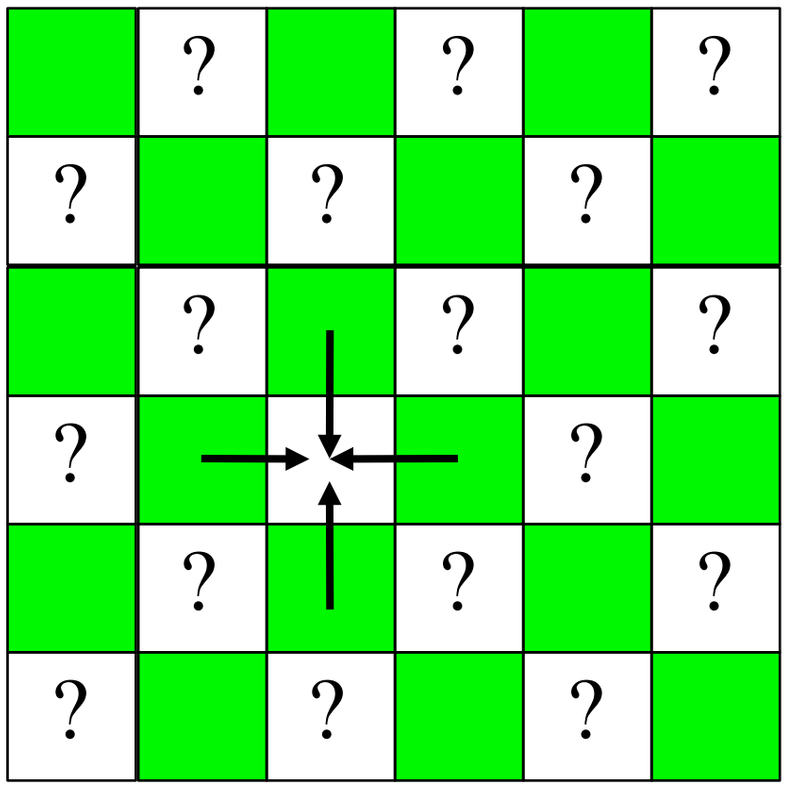
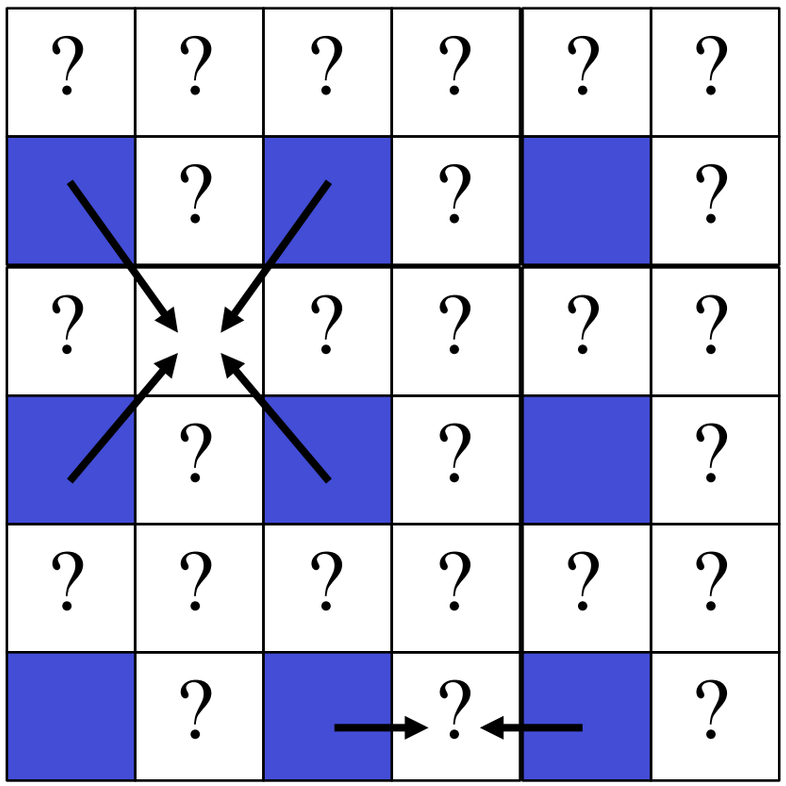
Naïve full-resolution interpolation

- **What if we don't want to throw away so much sharpness?**







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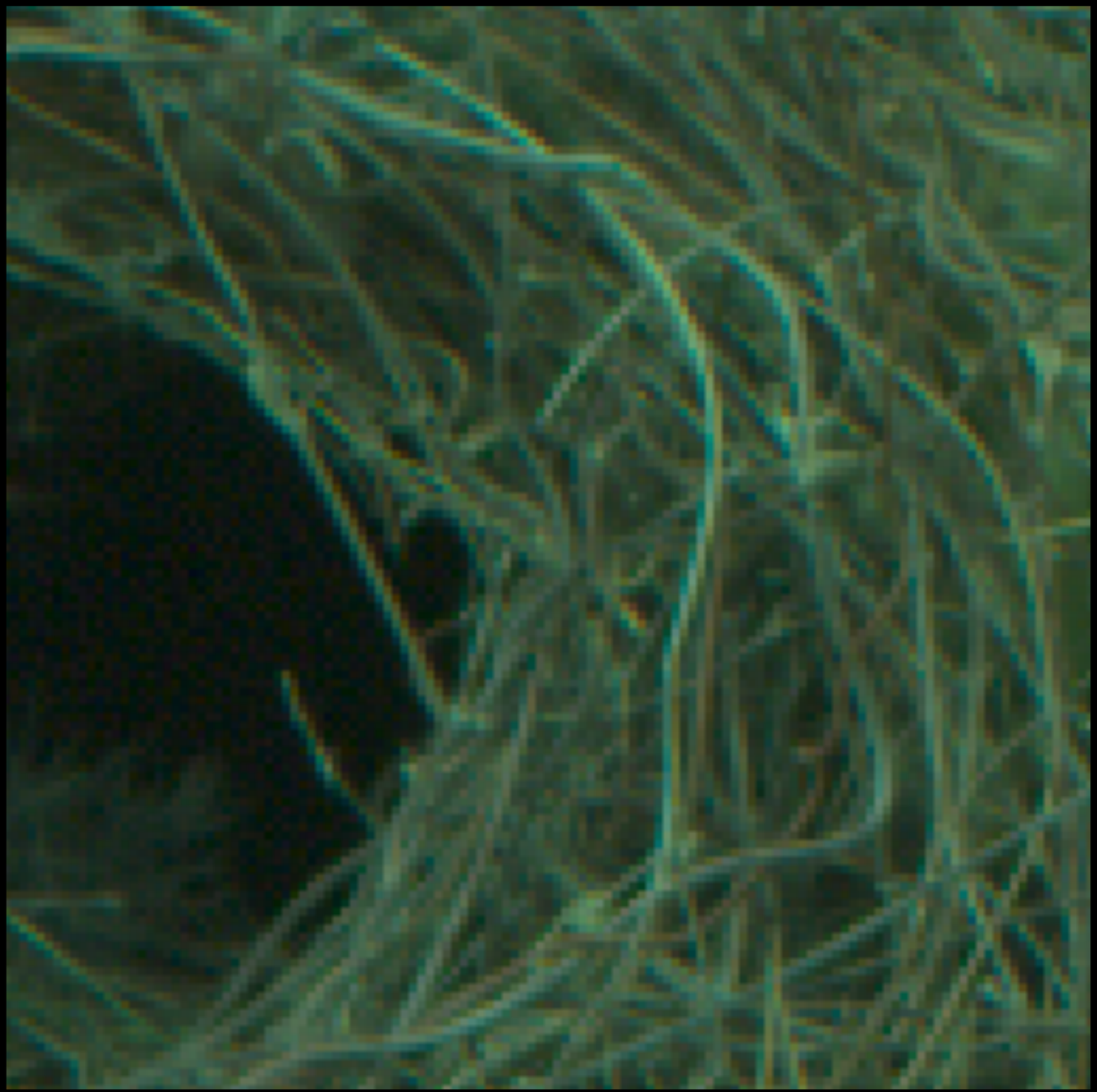

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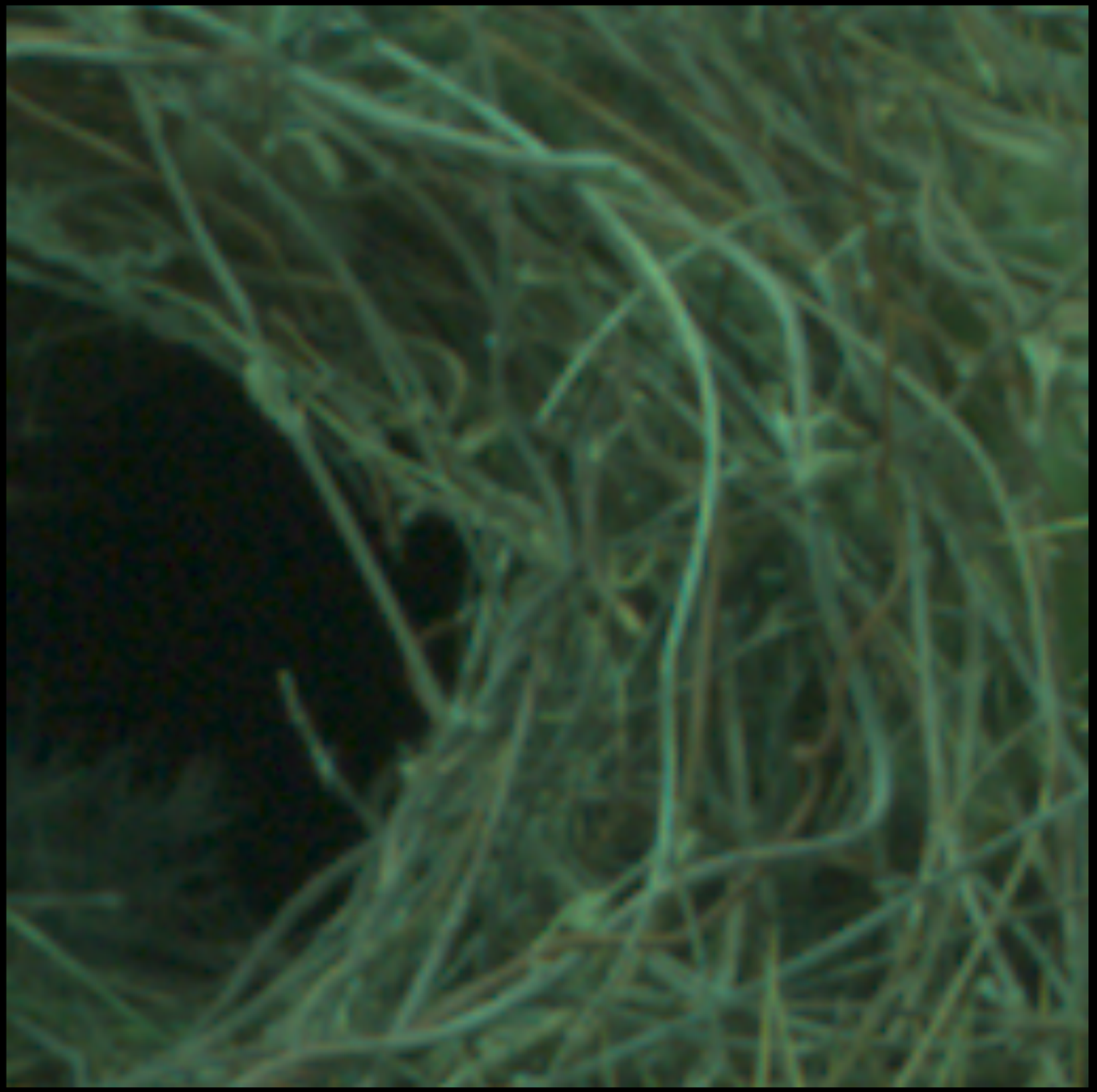
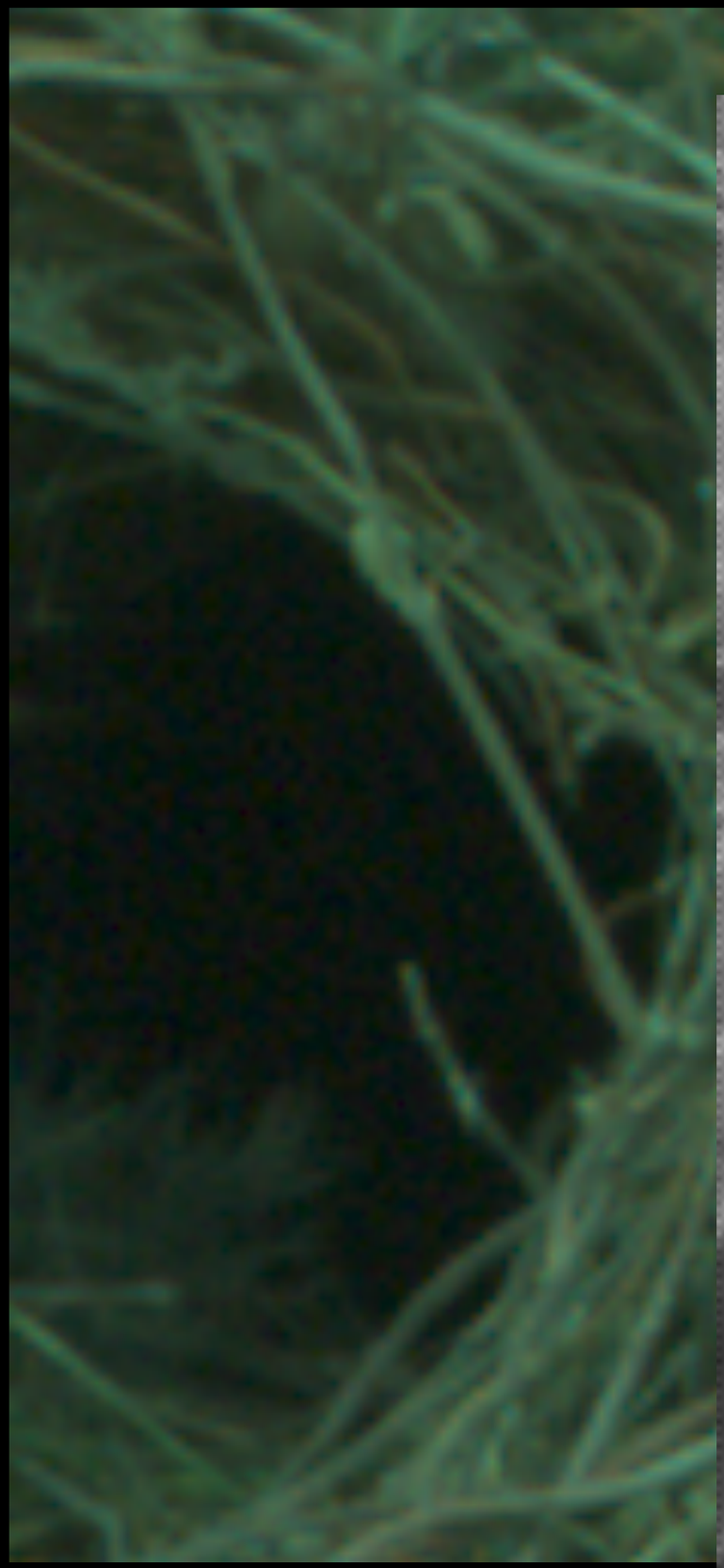
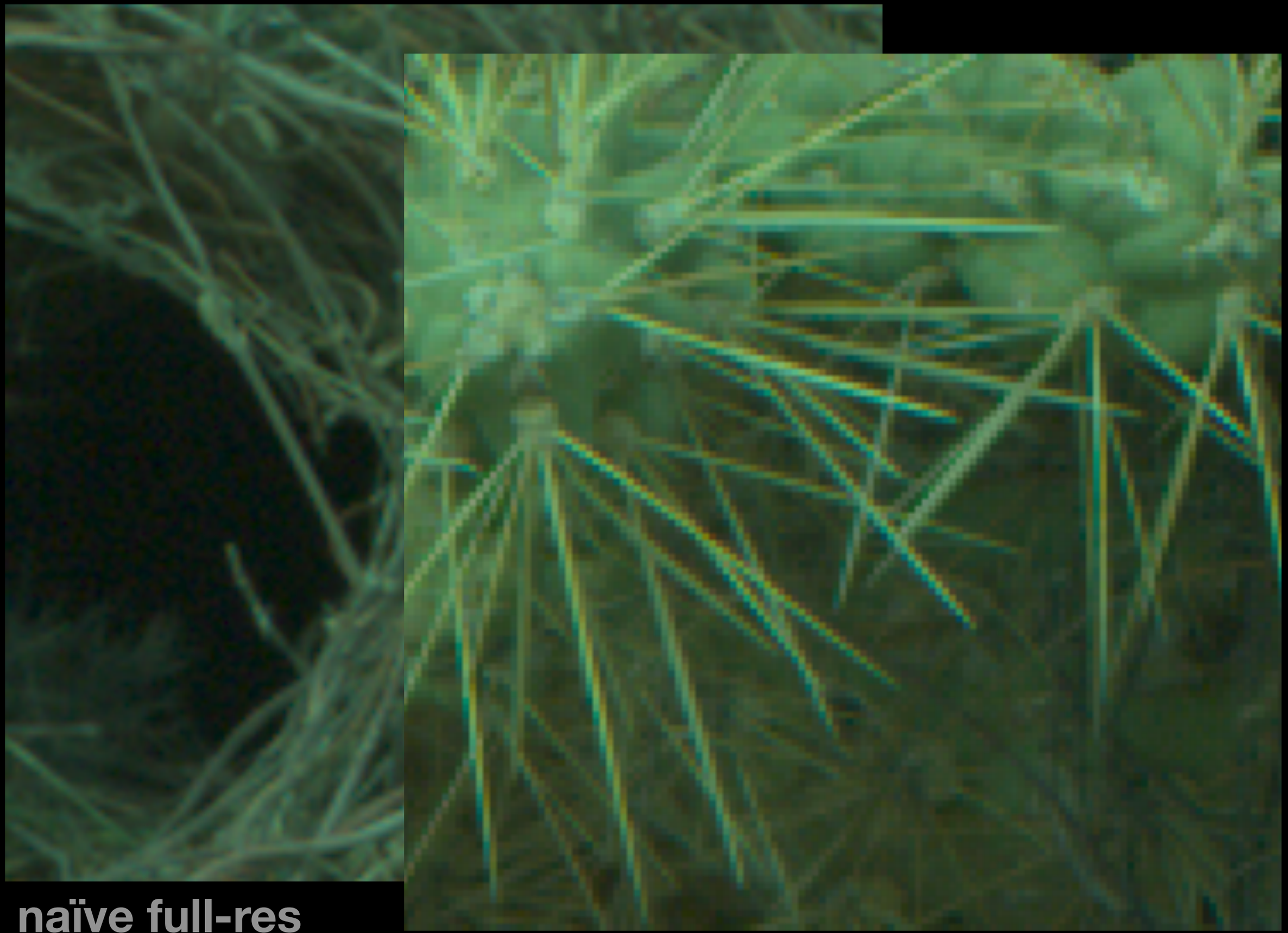


naïve full-res



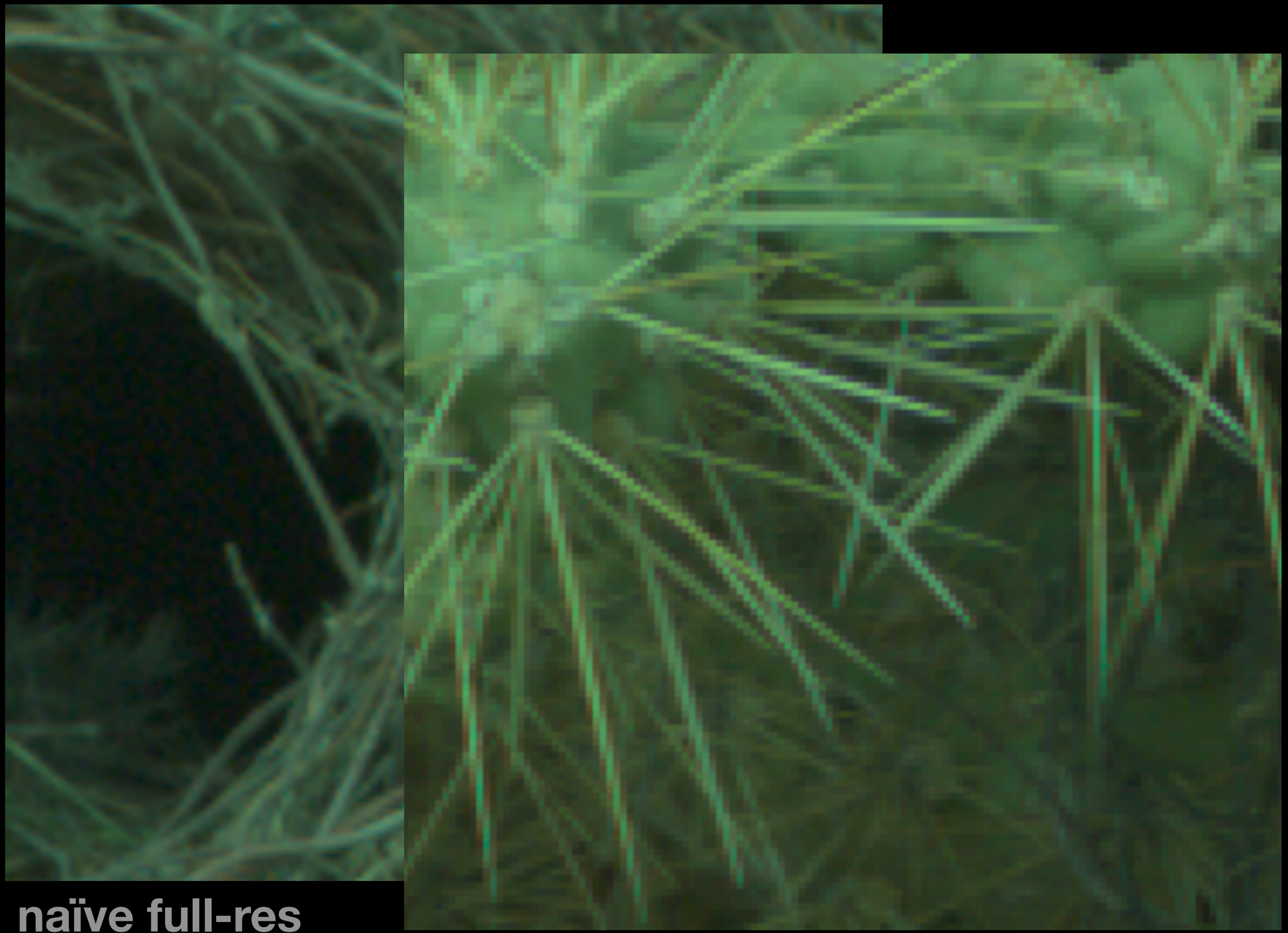
naïve full-res

bayer



naïve full-res

block



naïve full-res

centered

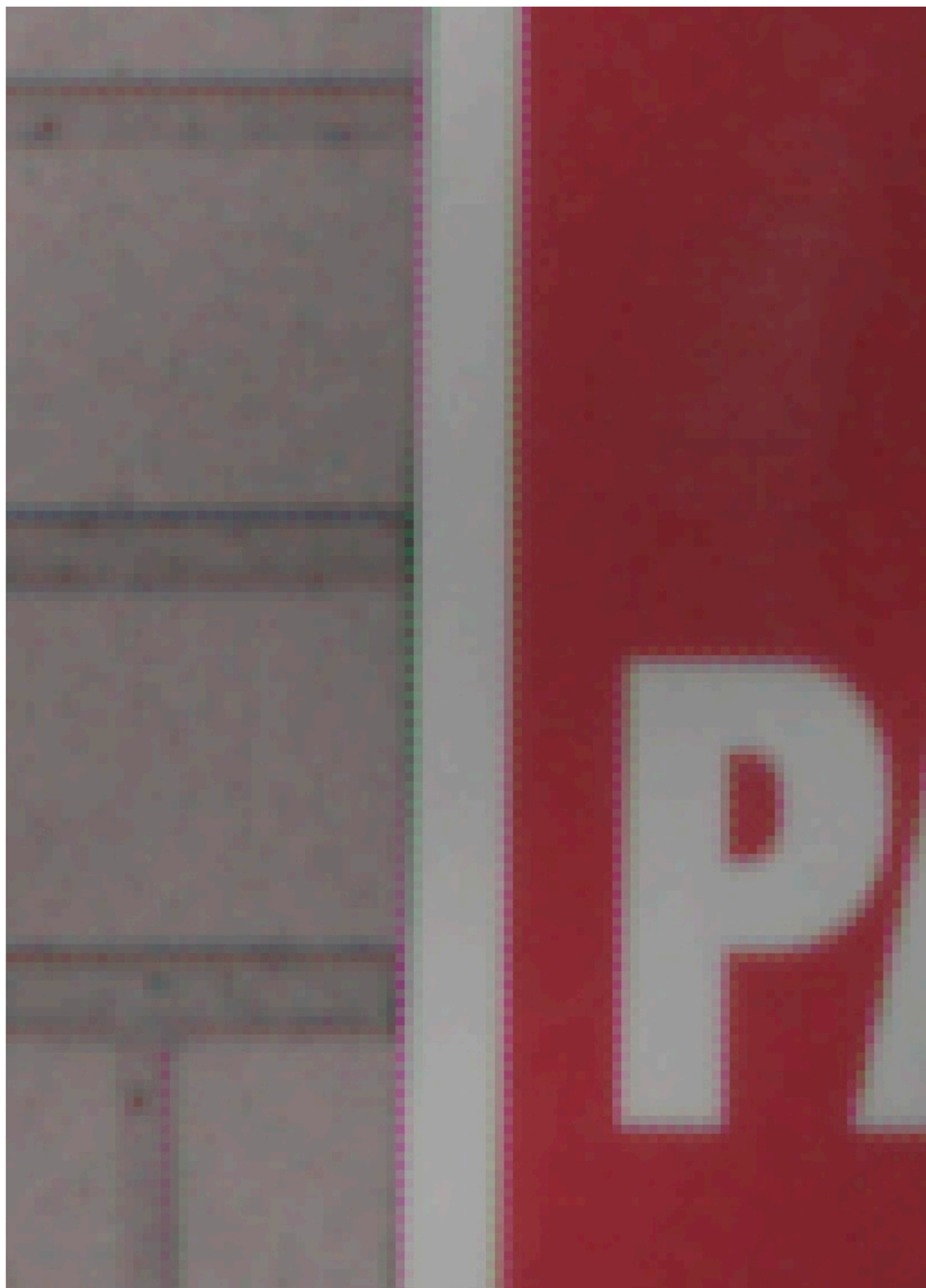
naïve full-res

naïve full-res

Results of simple linear

slide by Frédo Durand, MIT

Results - not perfect



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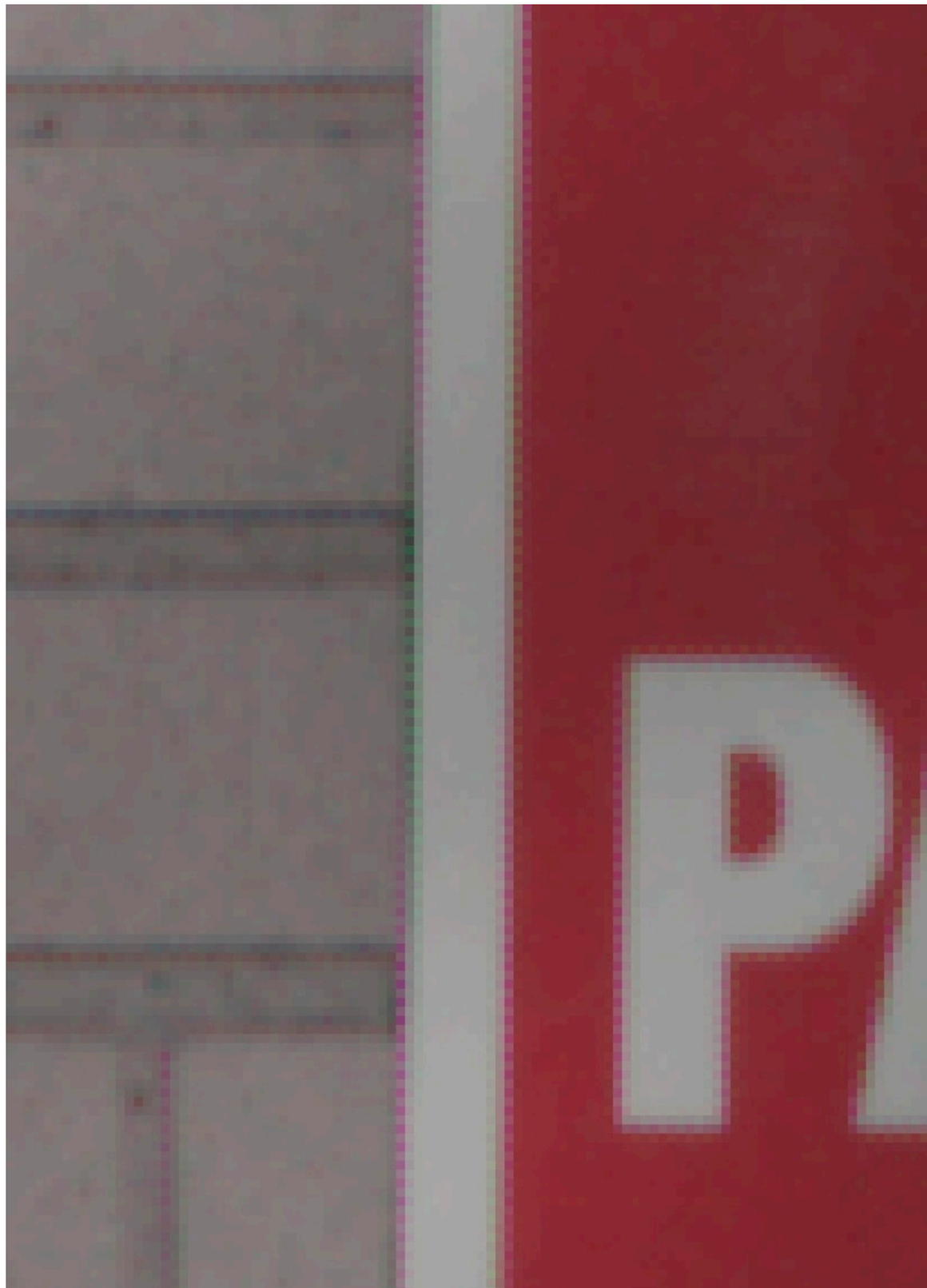
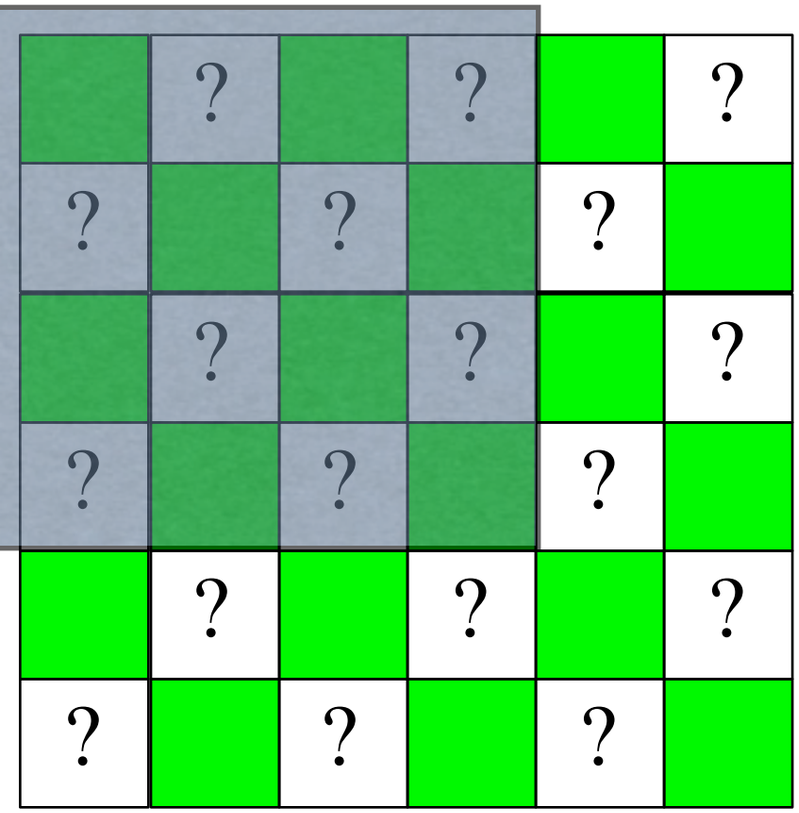
Questions?



The problem

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



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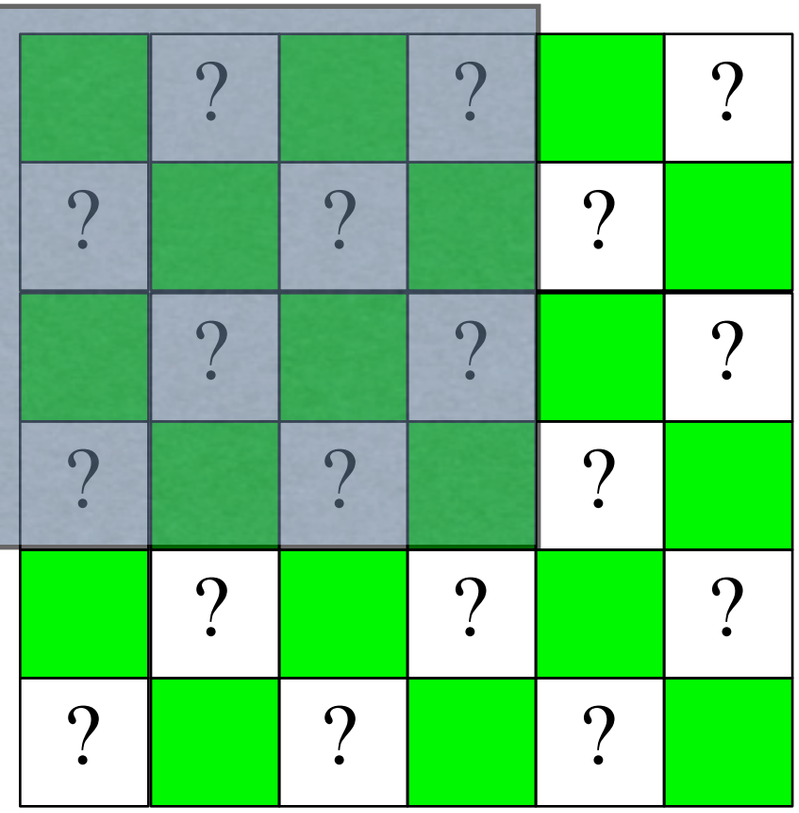

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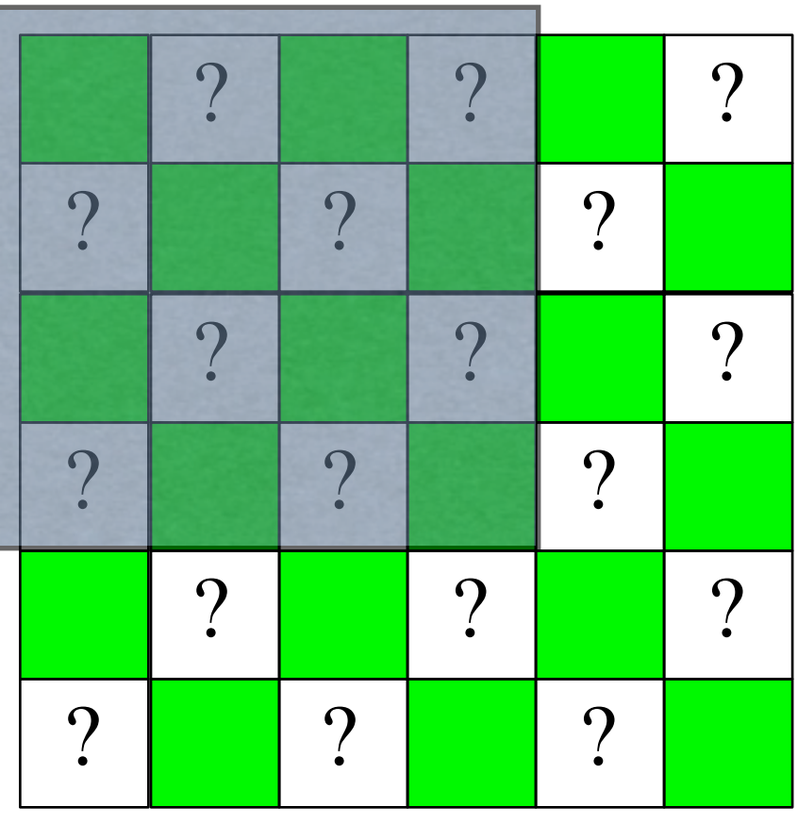

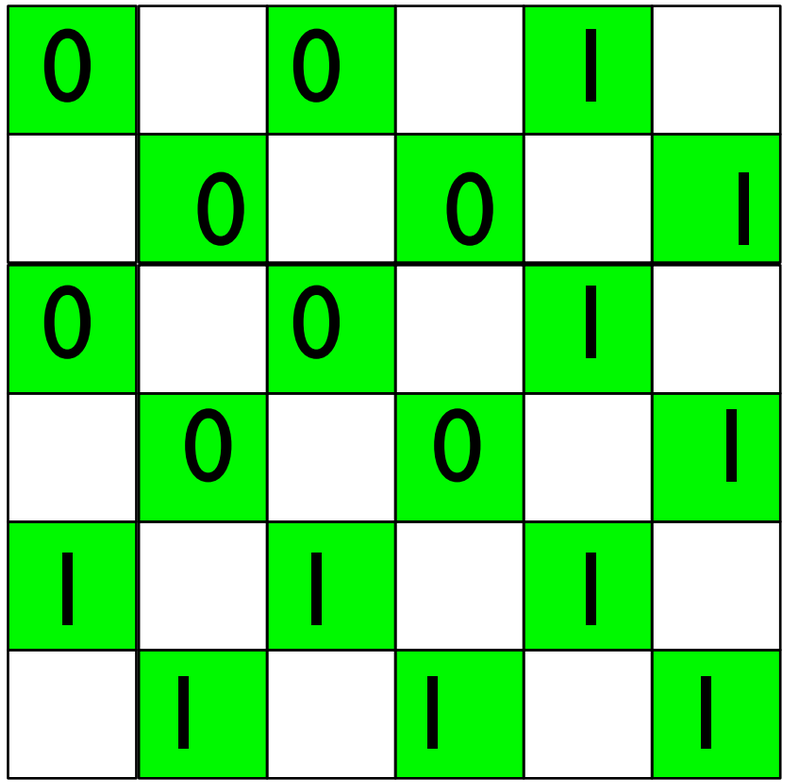

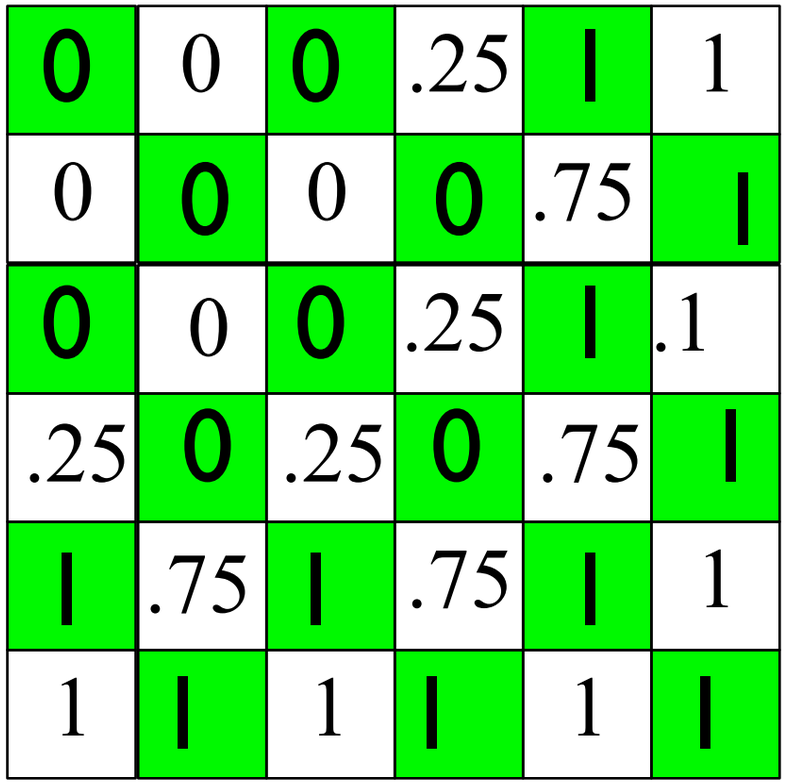

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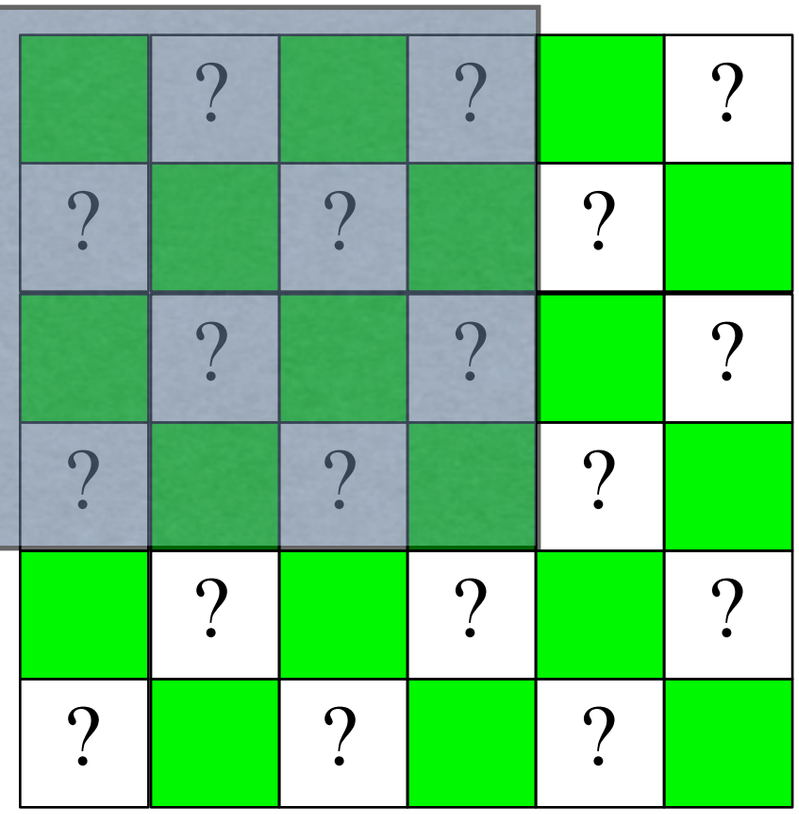

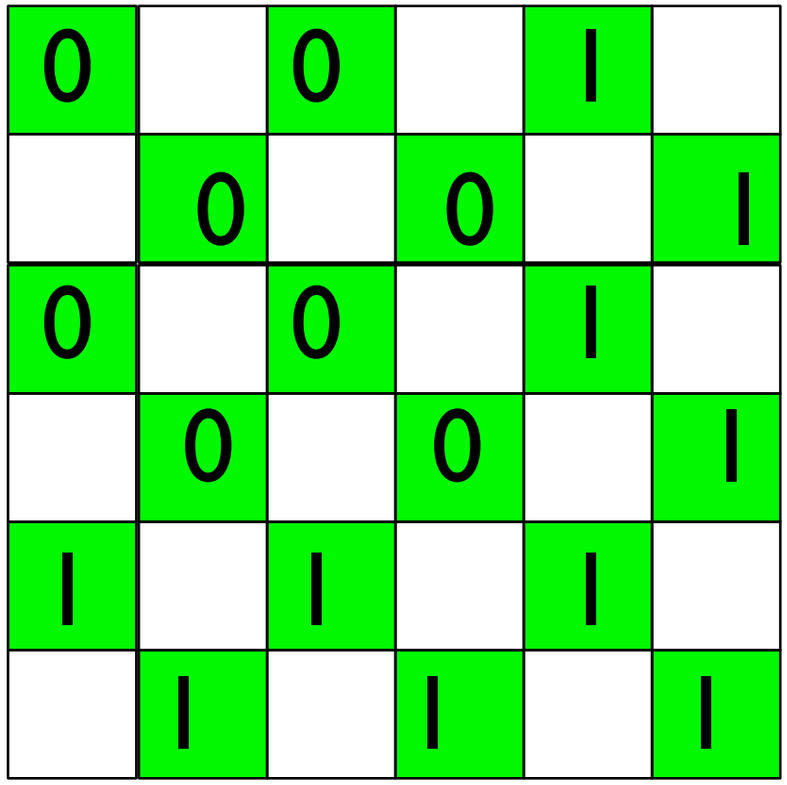

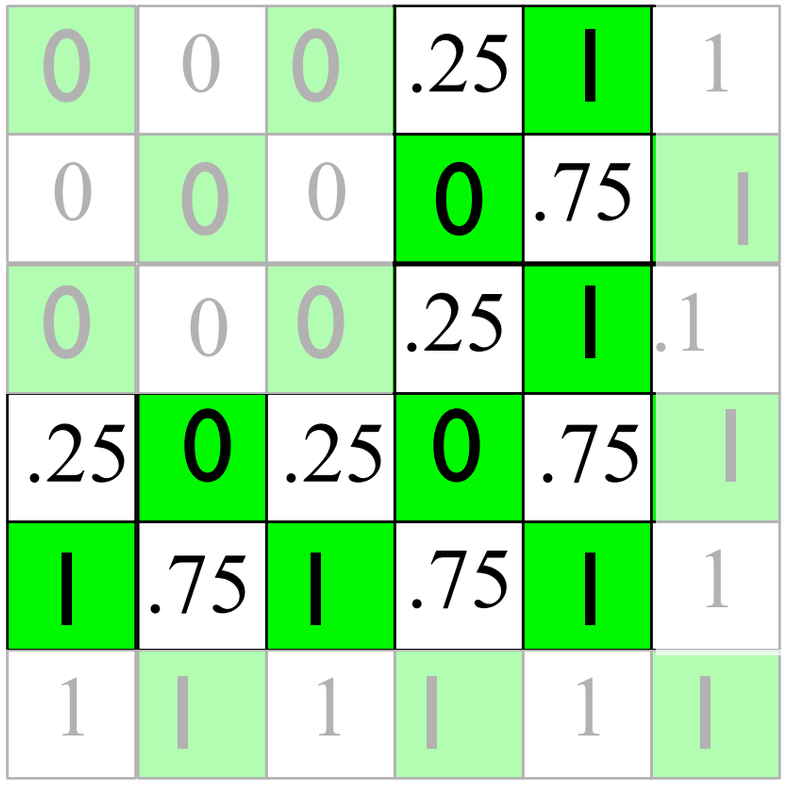

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Yep, that's what we saw

Green channel

Edge-based Demosaicking

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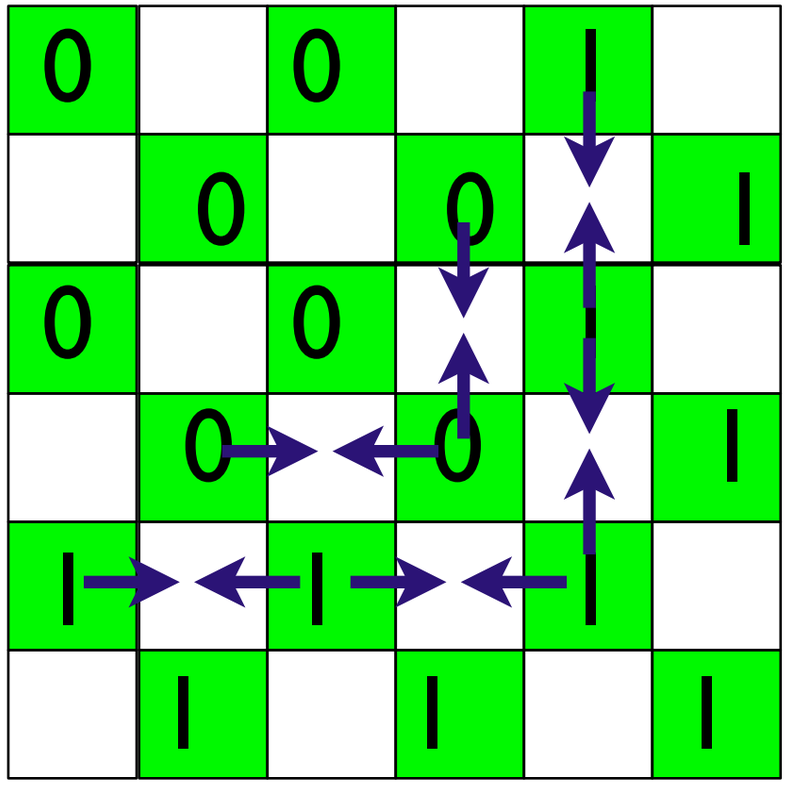
Idea

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



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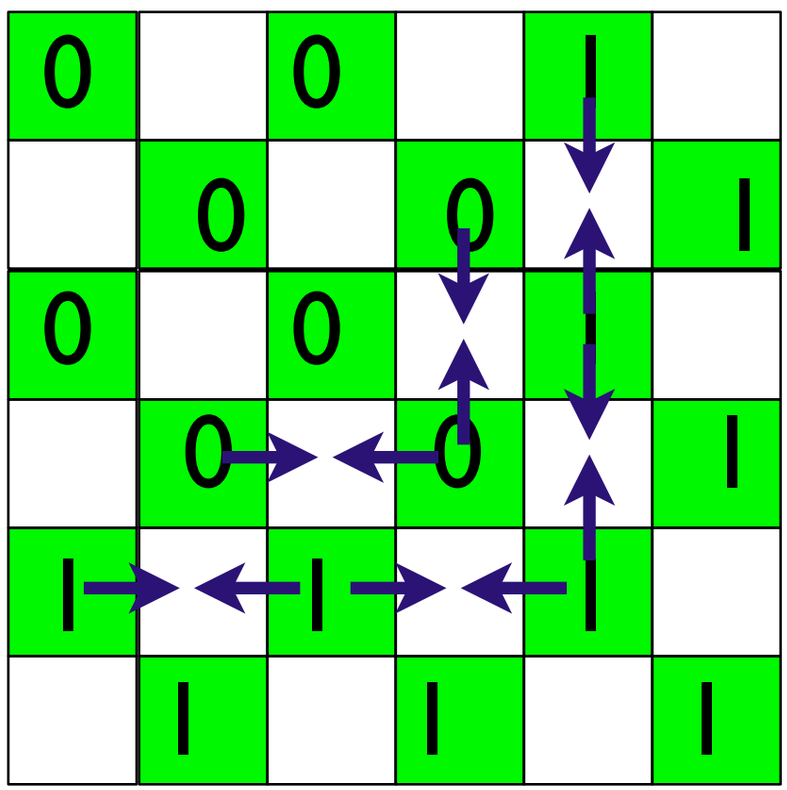
How do we decide

- Look at the similarity of recorded neighbors
  - Compare |up-down| and |right-left|
  - Be smart
  - See pset 4

- Called edge-based demosaicking



Green channel -- naive

slide by Frédo Dura

Green channel -- edge-based

Challenge with other channels

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slide by Frédo Durand, MIT

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

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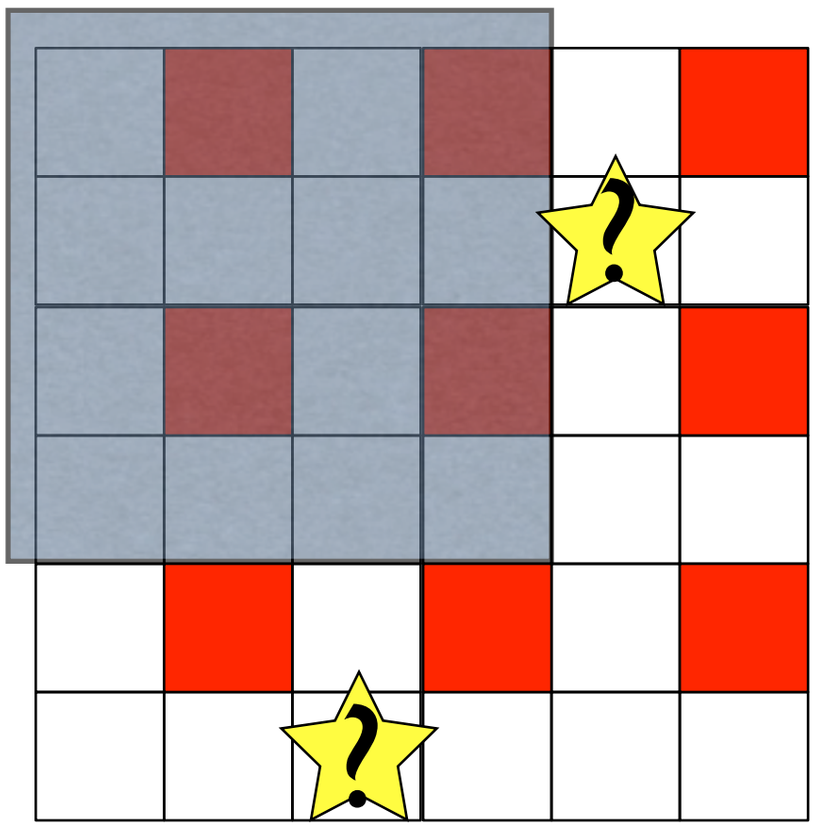
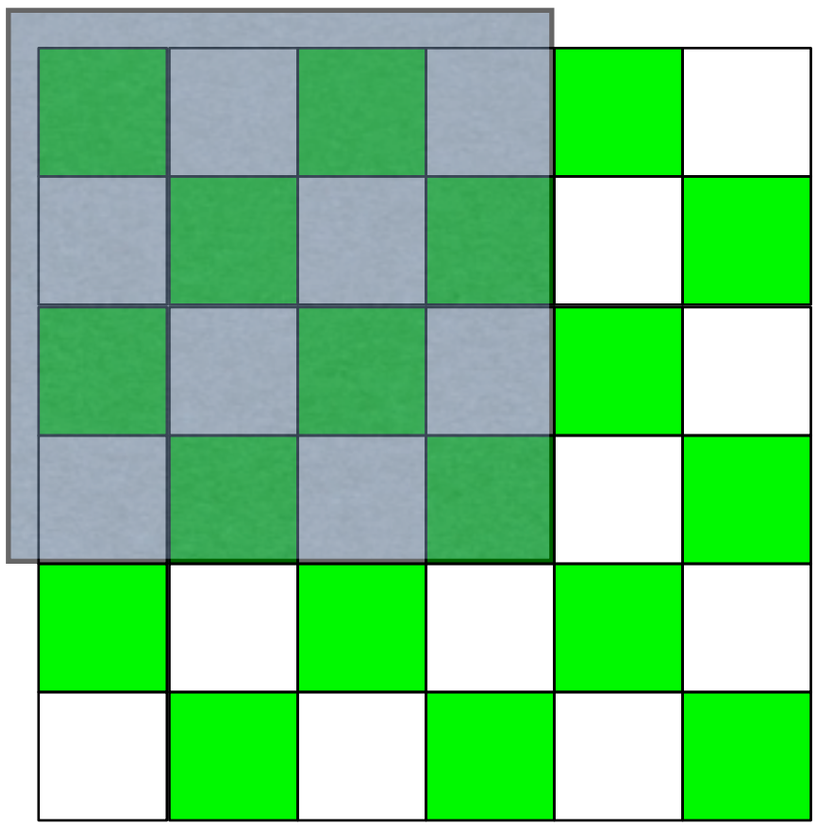
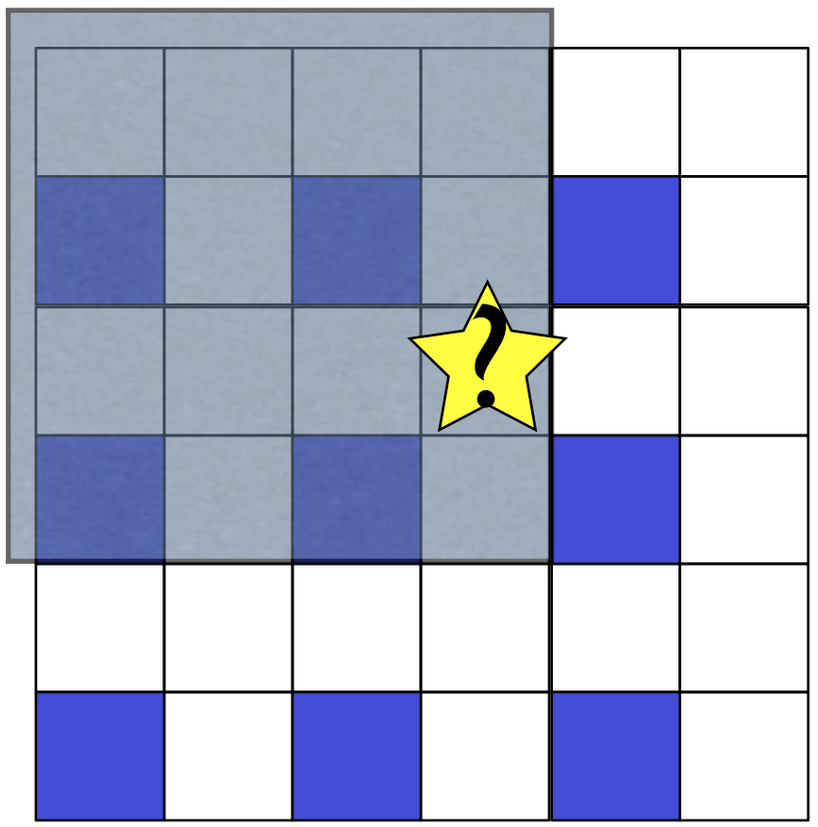
Example

- Black on white corner
- Notion of edge-based unclear for pixels in empty rows or columns







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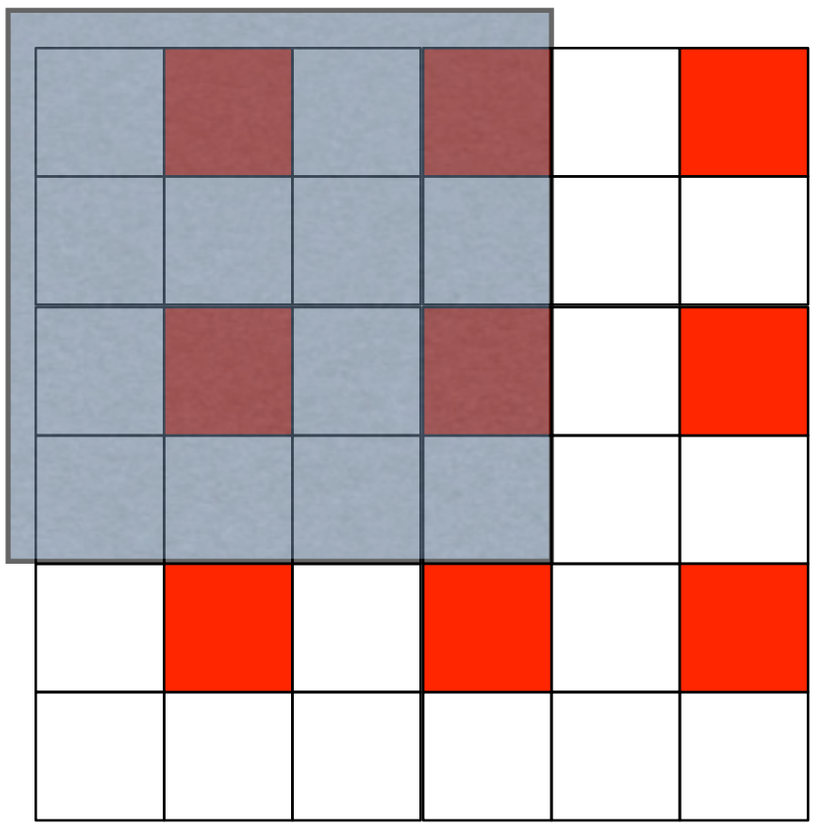
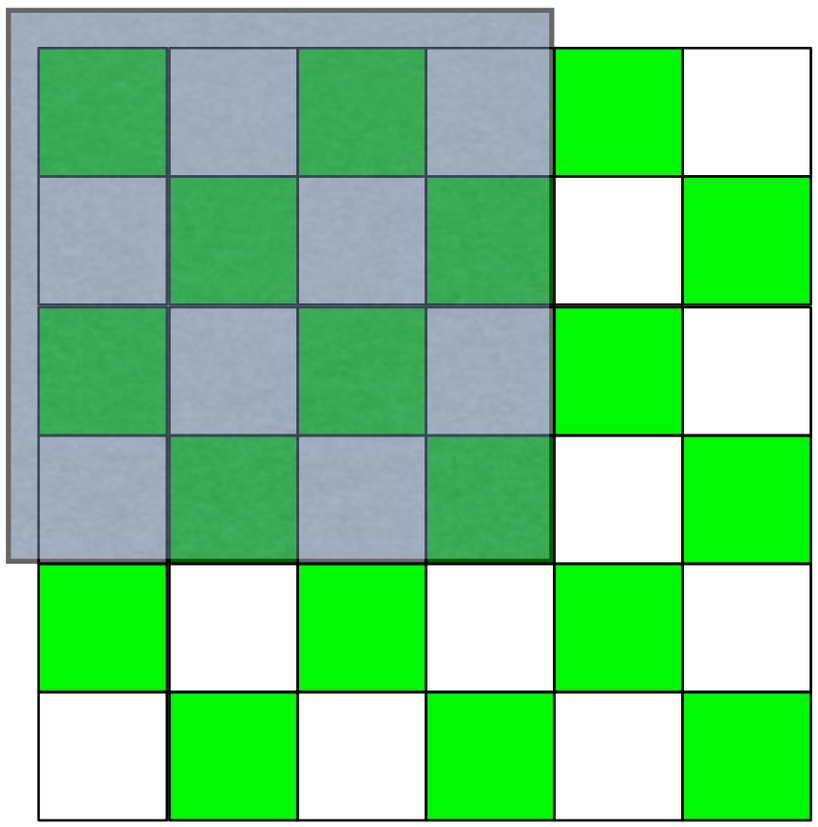
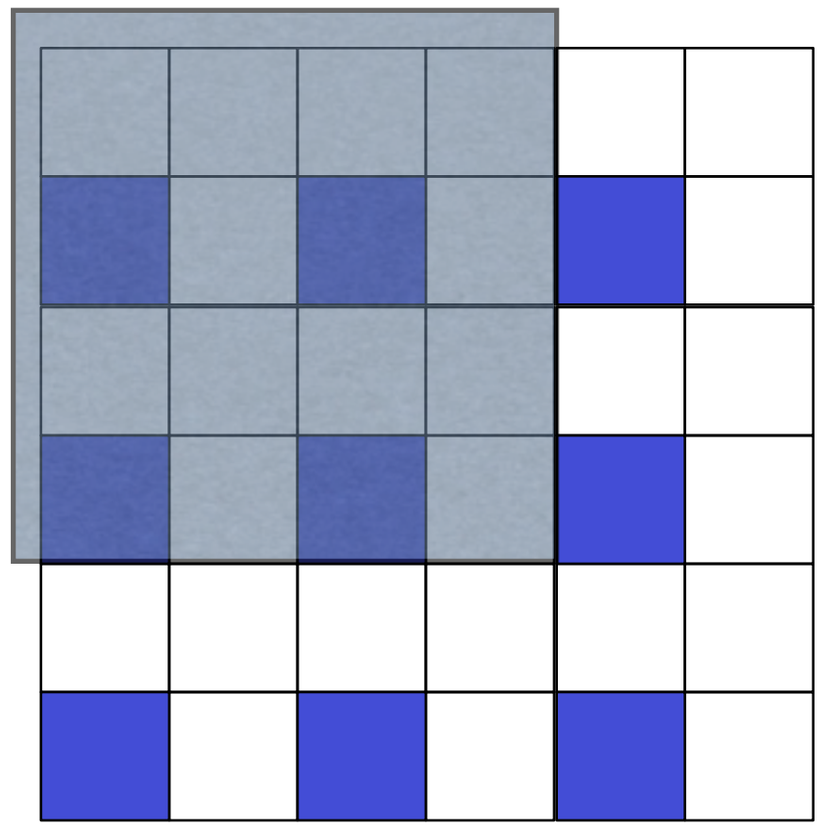
Example

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







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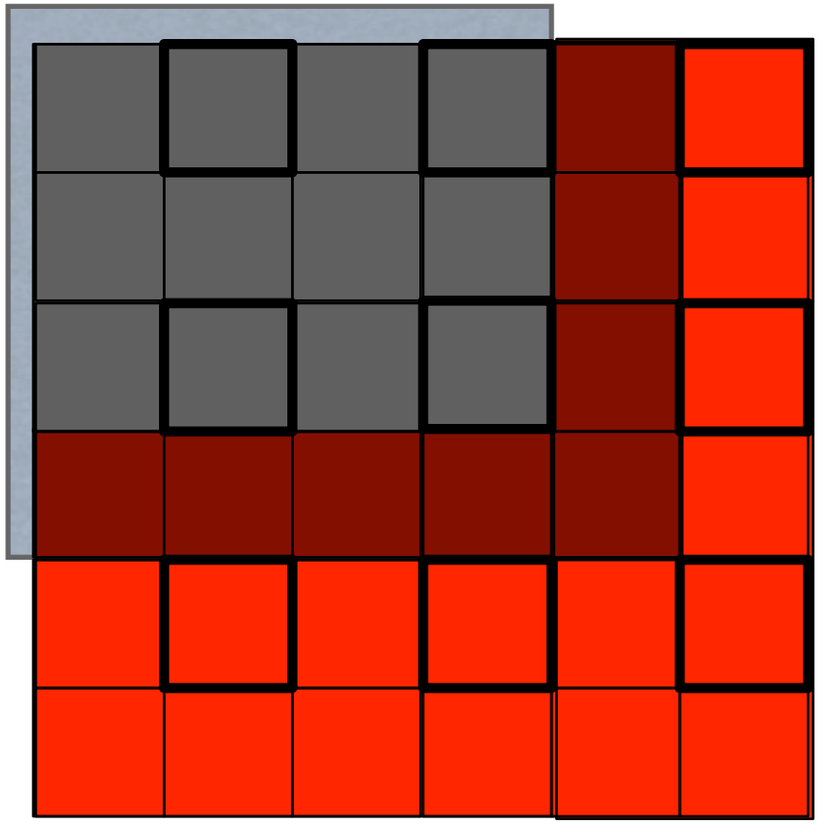
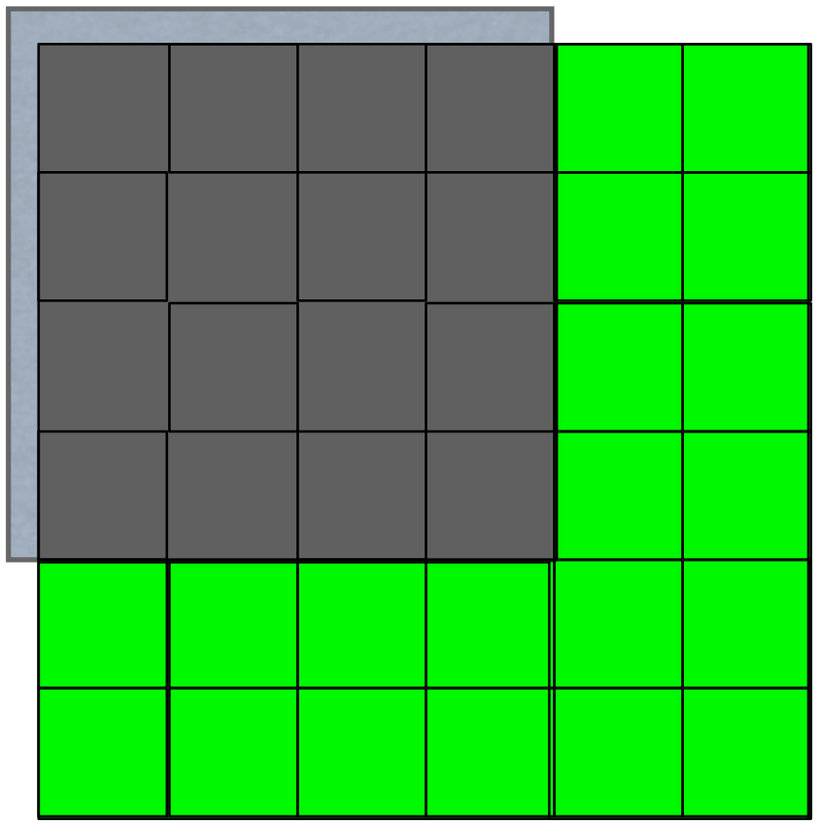
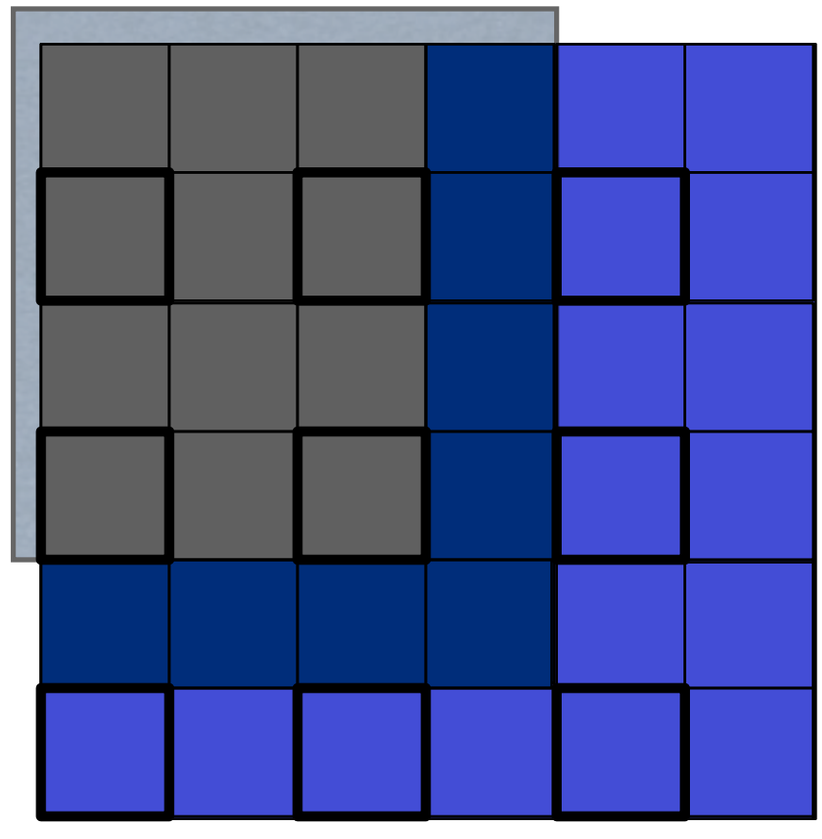
Example

- 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

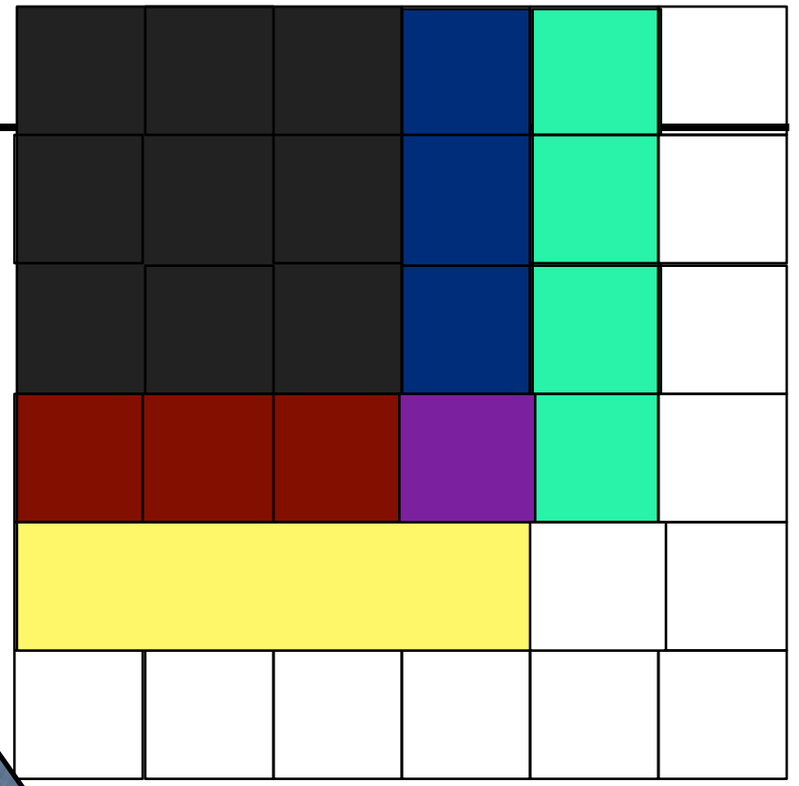


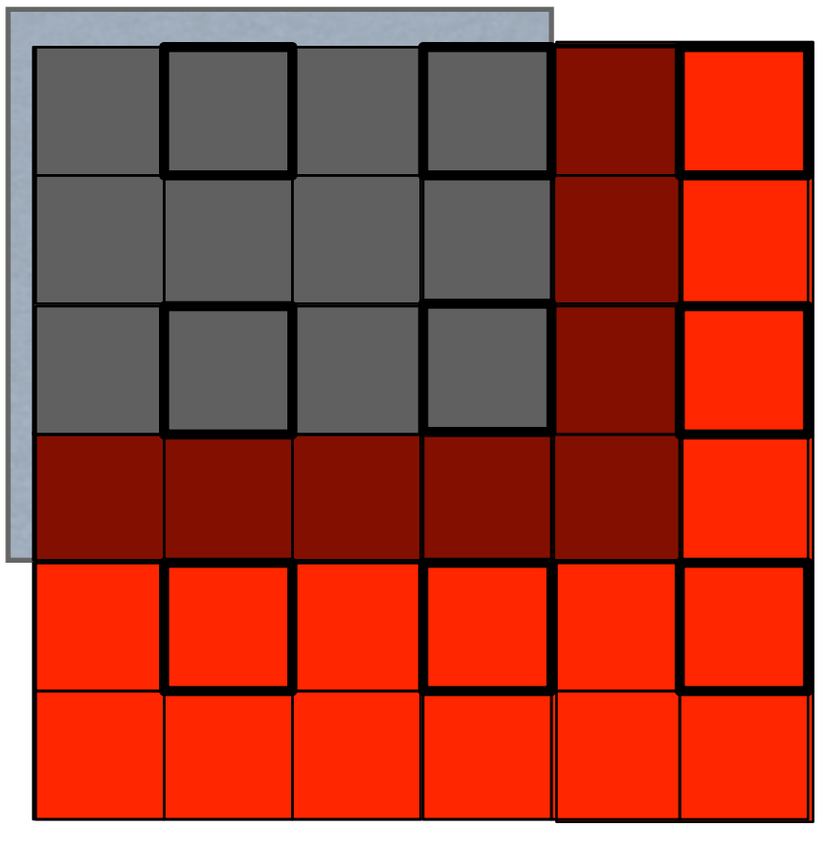


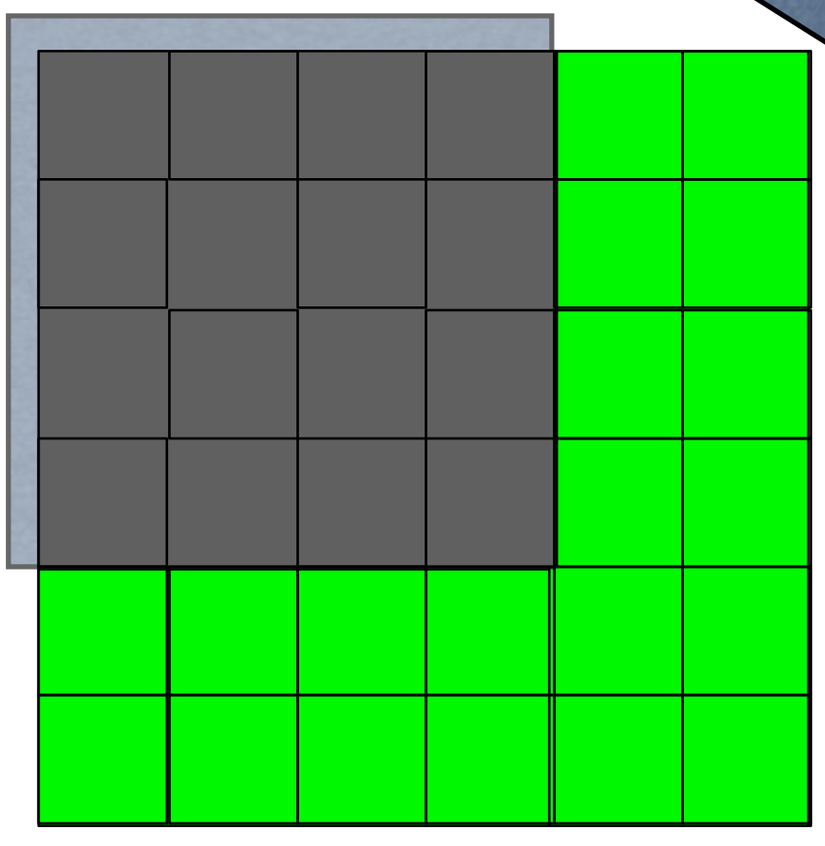


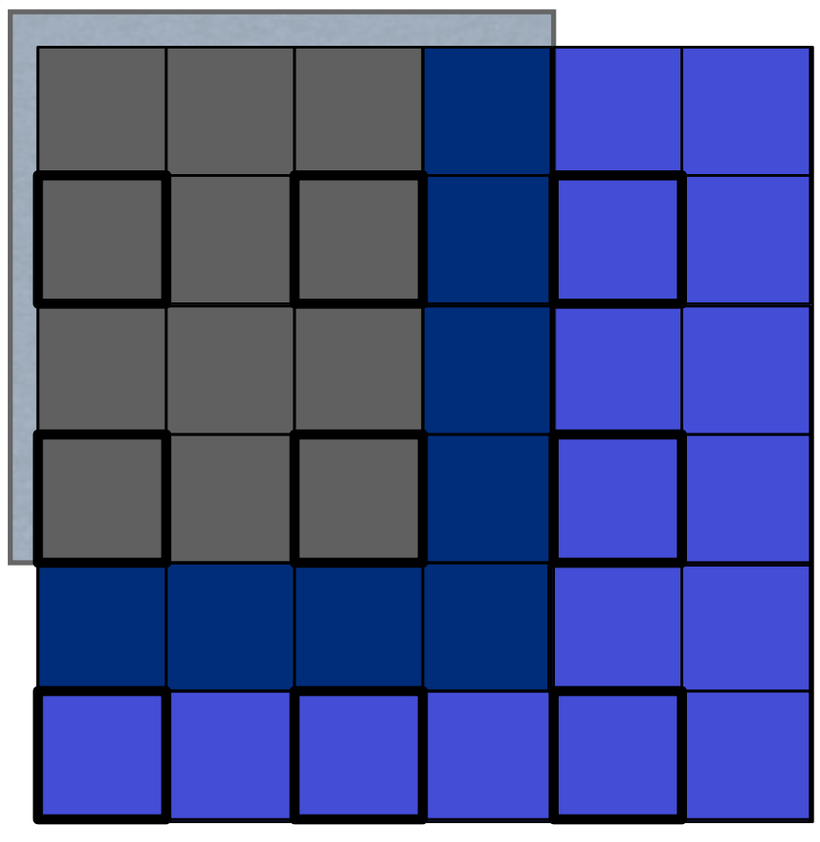
Example

- Bad color fringes!









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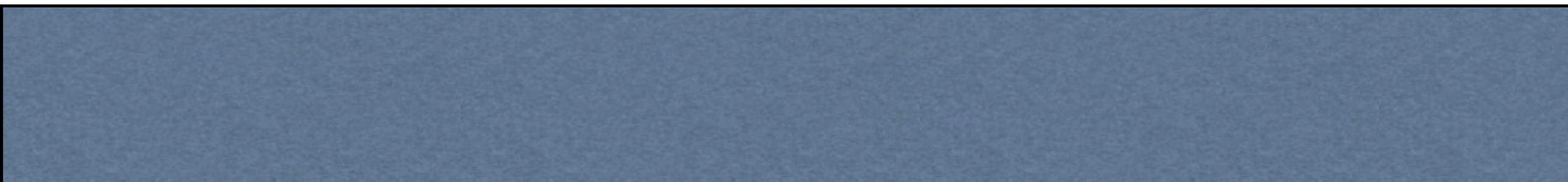
Recall color artifacts

Green-based Demosaicking



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Green-based demosaicking

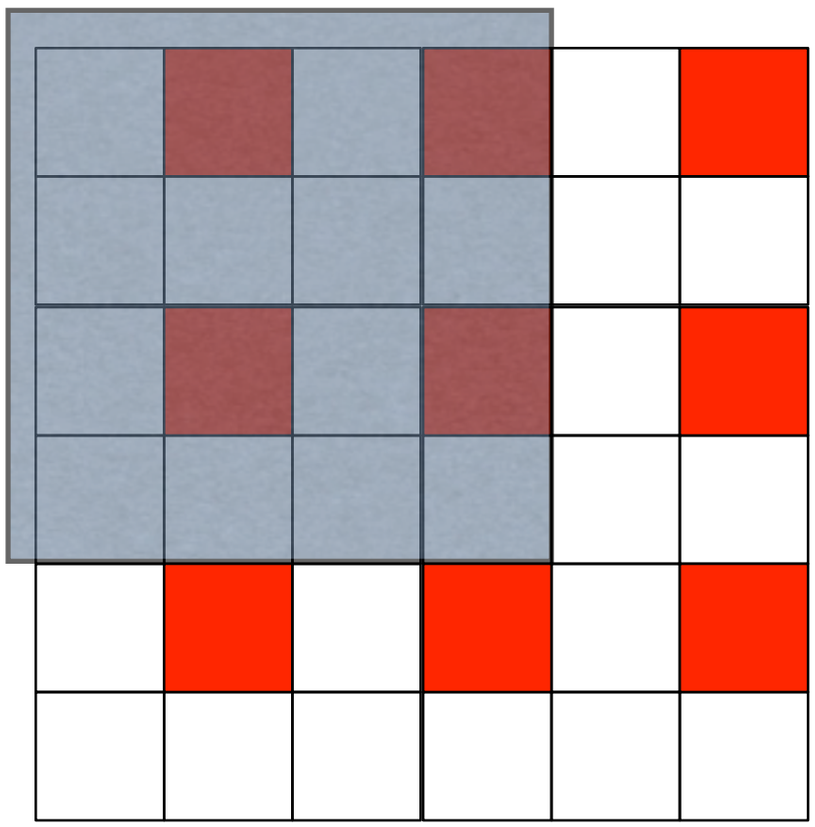
- **Green is a better color channel**
  - Twice as many pixels
  - Often better SNR
  - We know how to do edge-based green interpolation

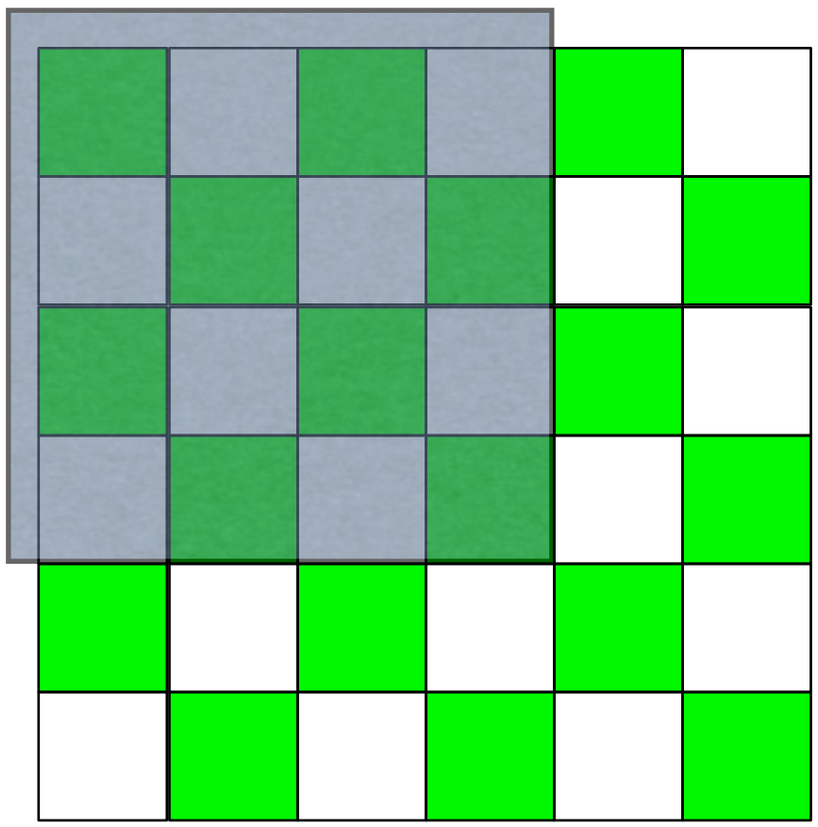
- **Do the best job you can and get high resolution from green**
- **Then use green to guide red & blue interpolation**

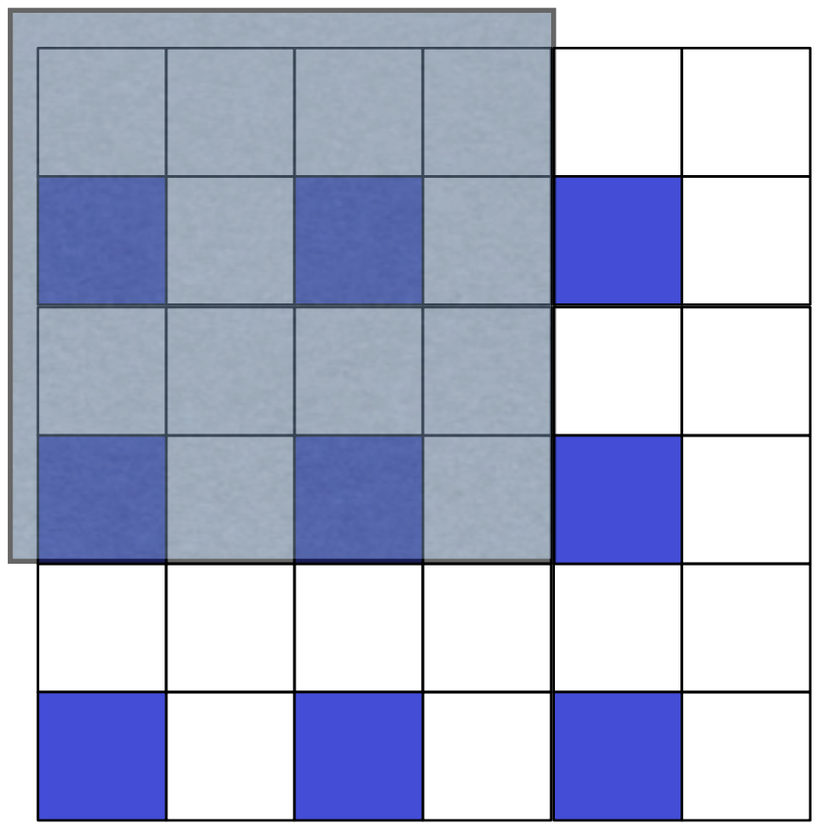
Interpolate difference to green

- 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

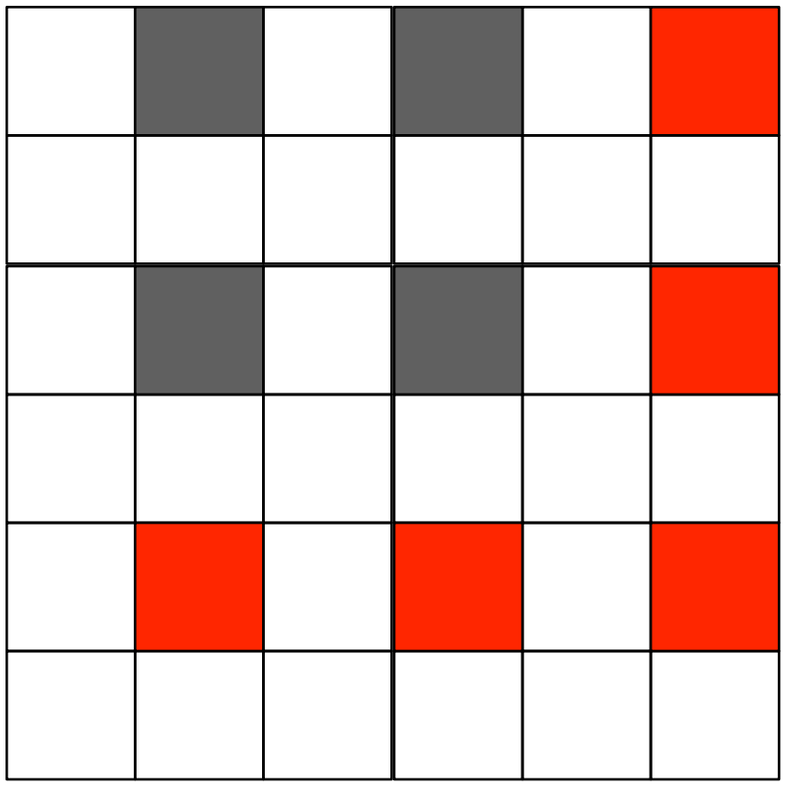
Black on white corner

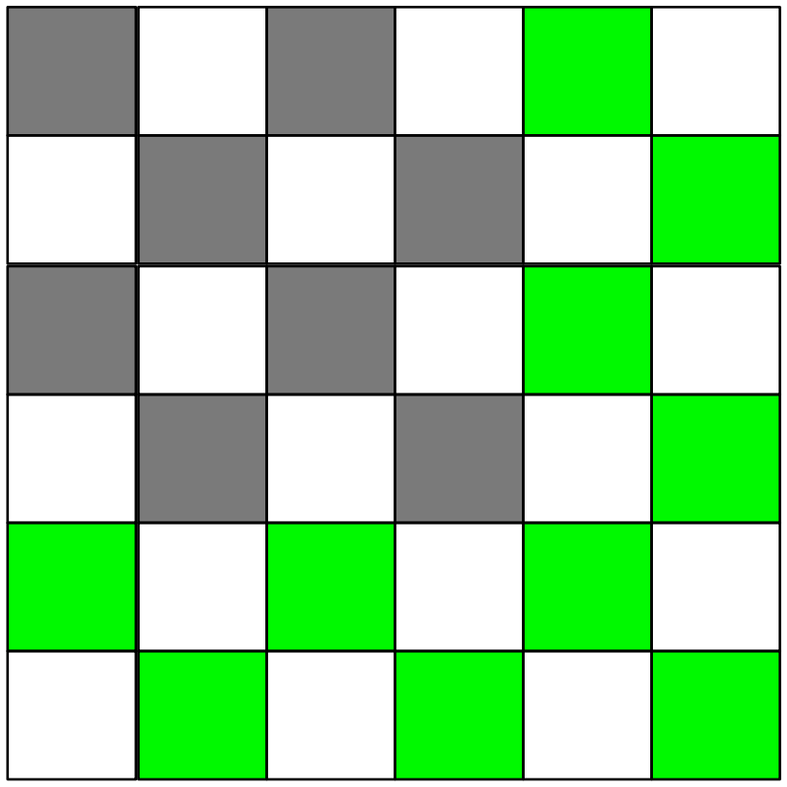


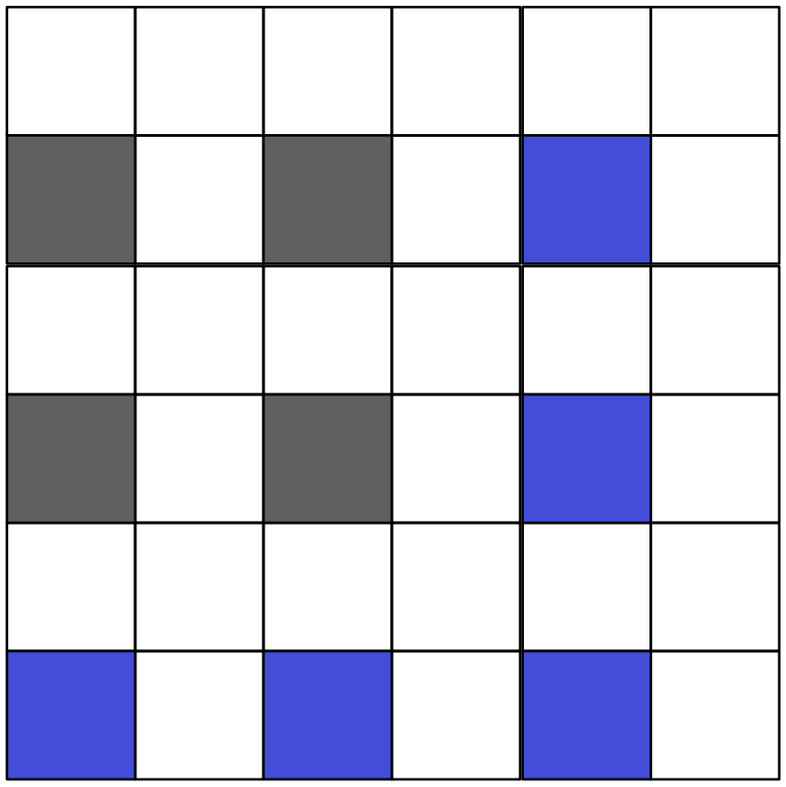




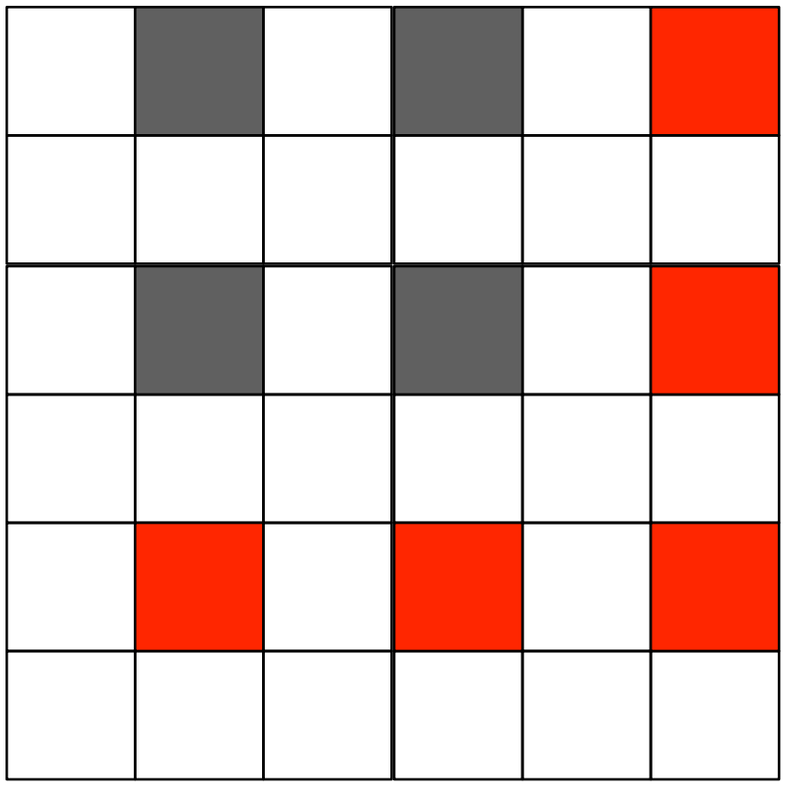
Measurements

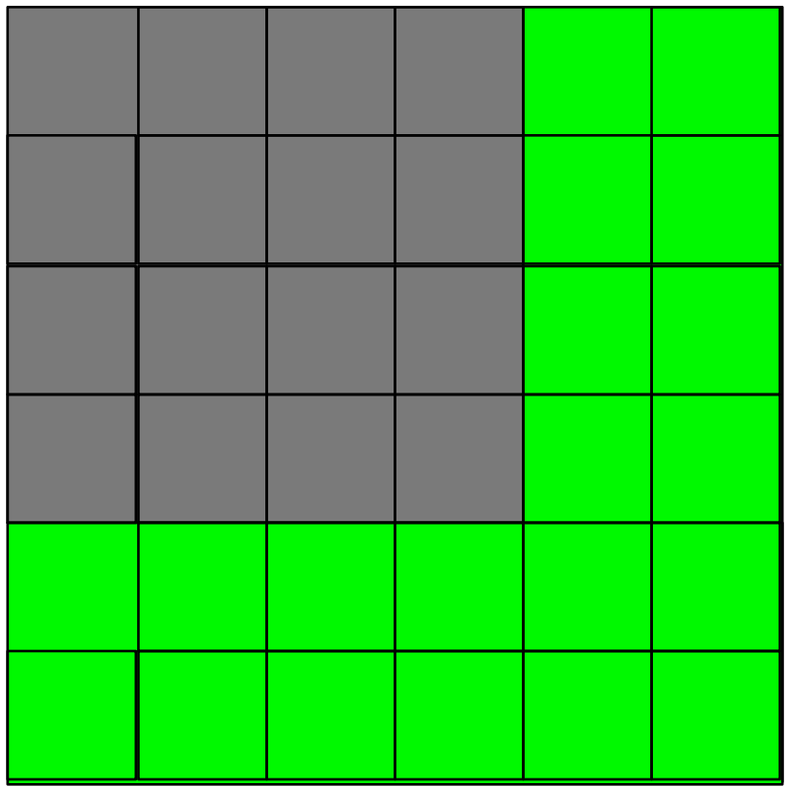


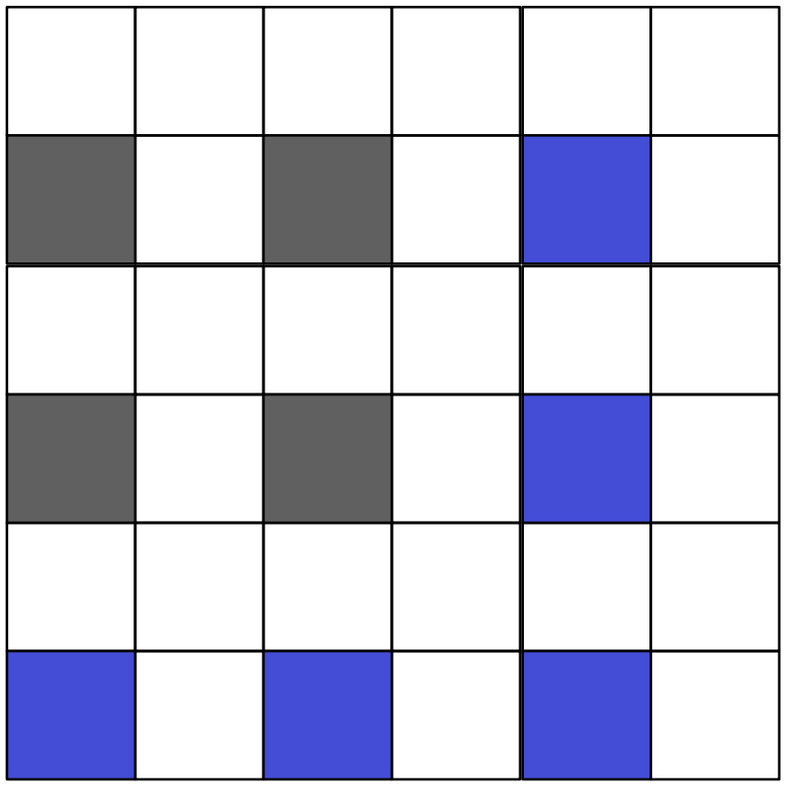




Edge-based green

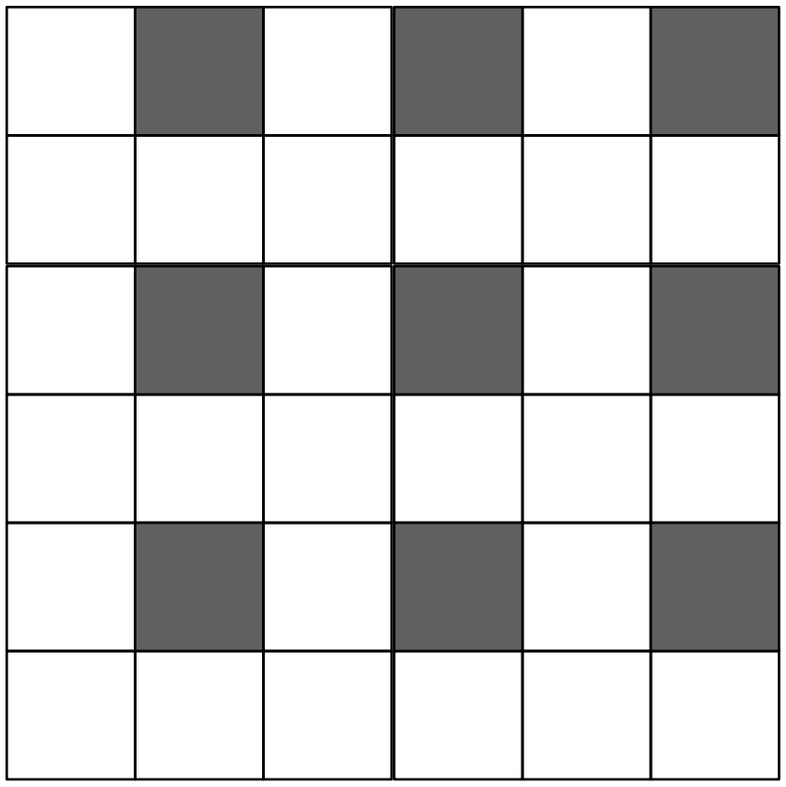


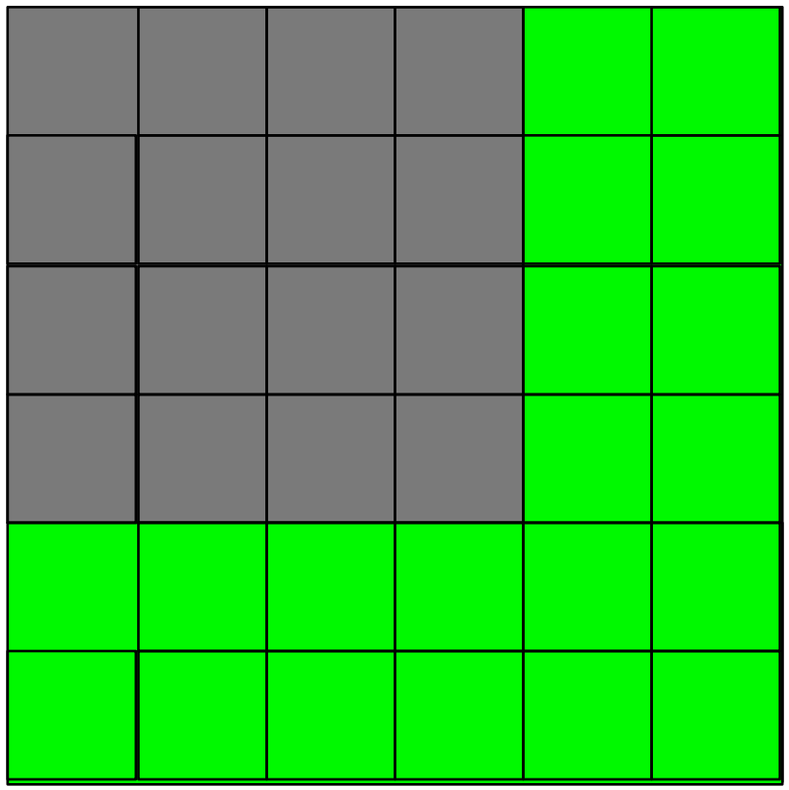


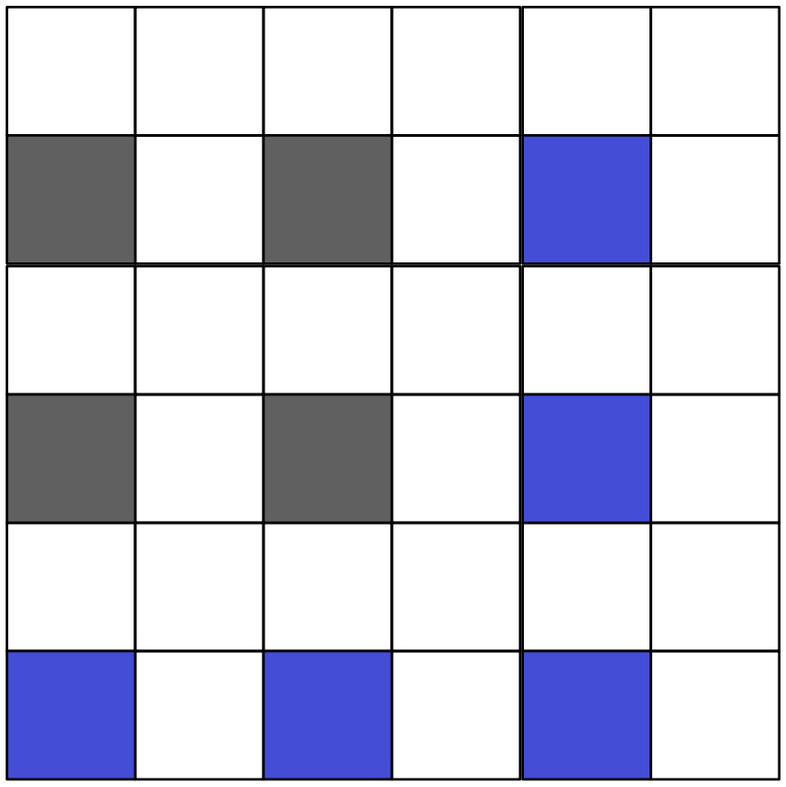


Red-Green difference

- Zero everywhere!

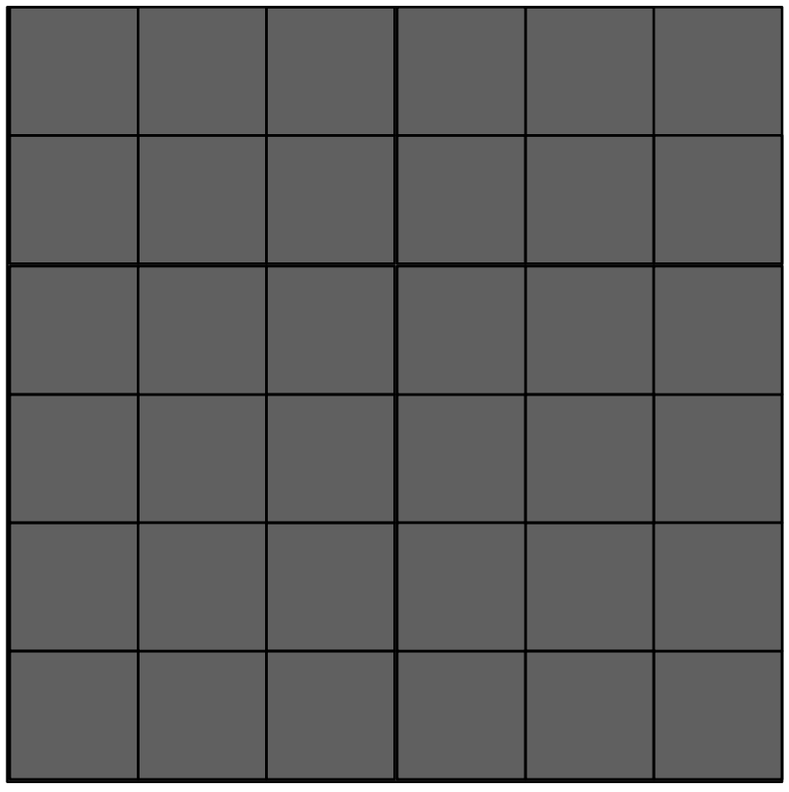


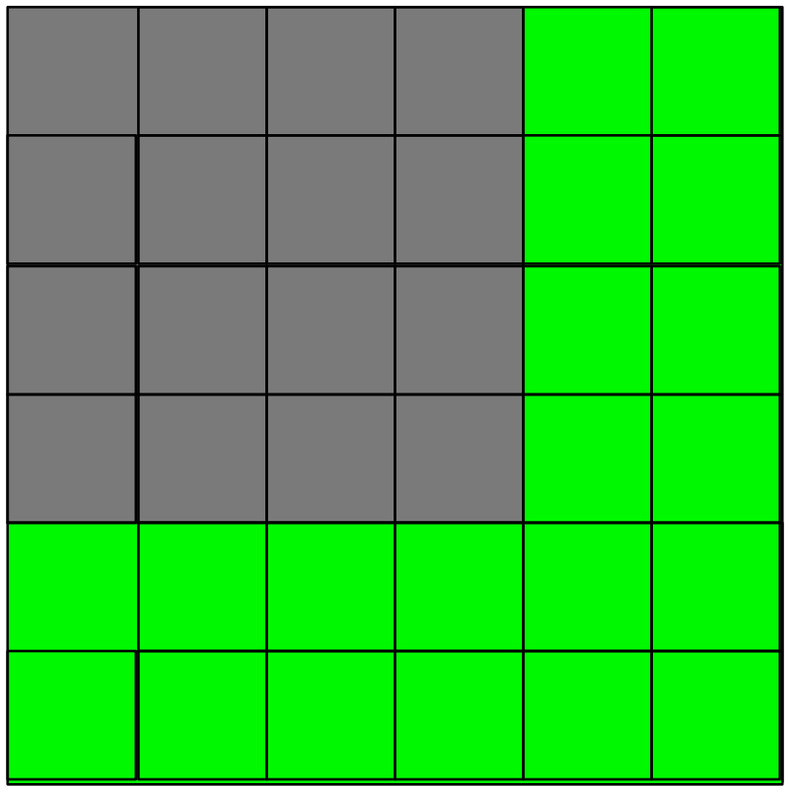


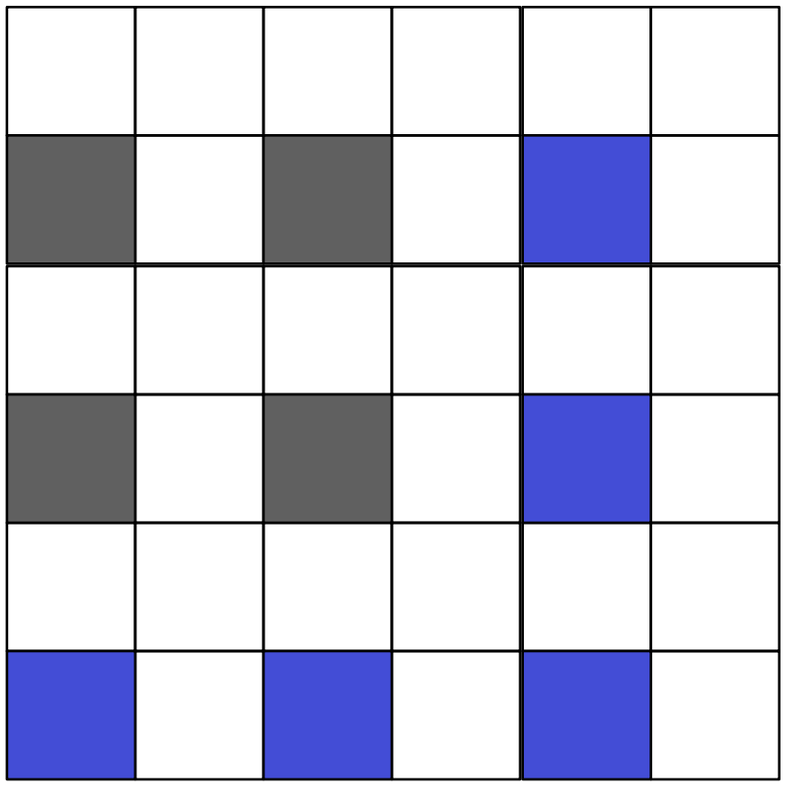


Red-Green interpolation

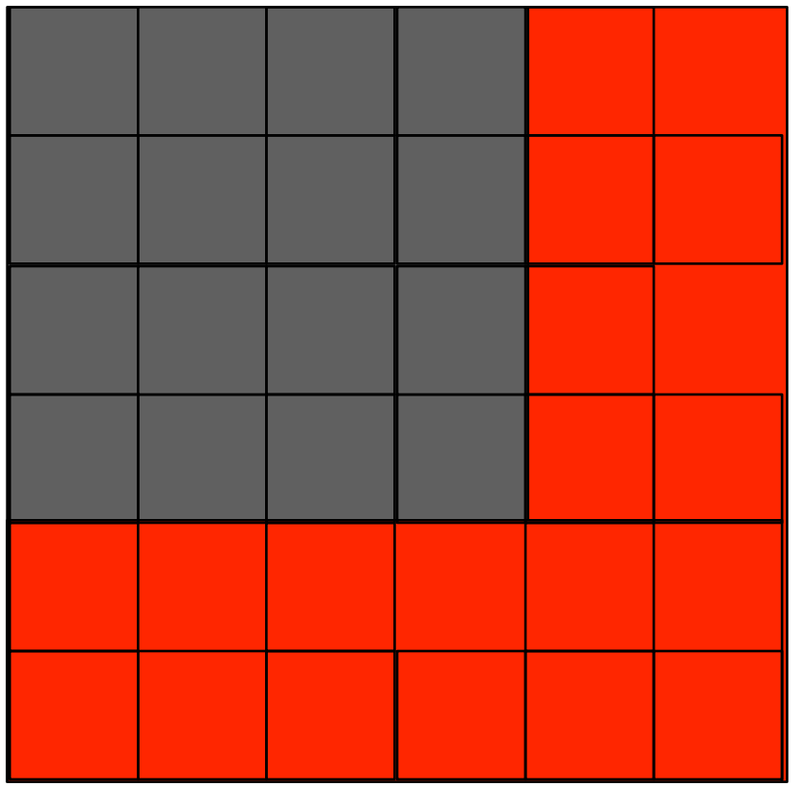
- Easy!

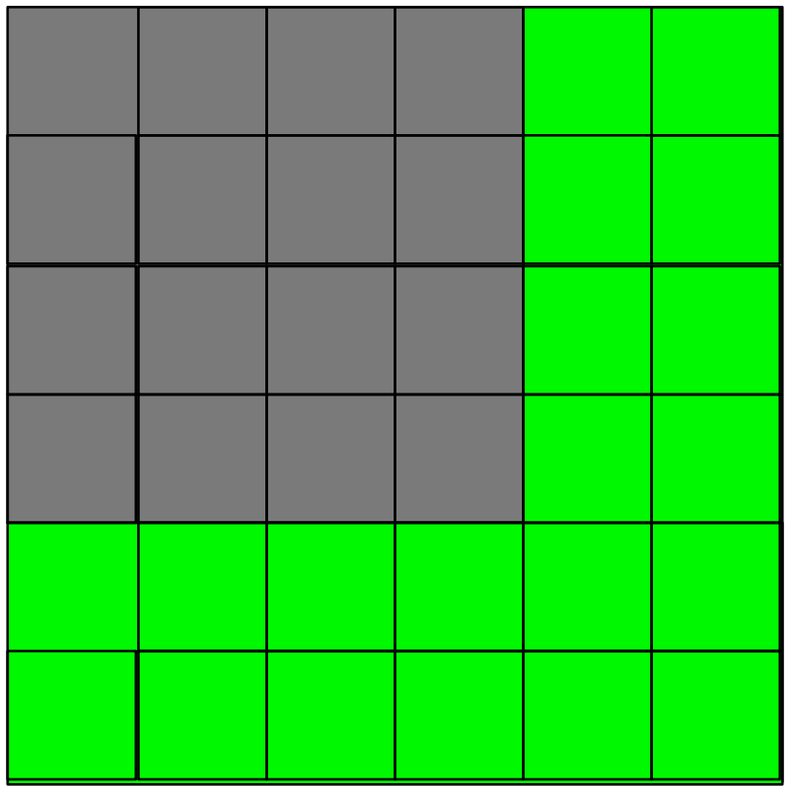


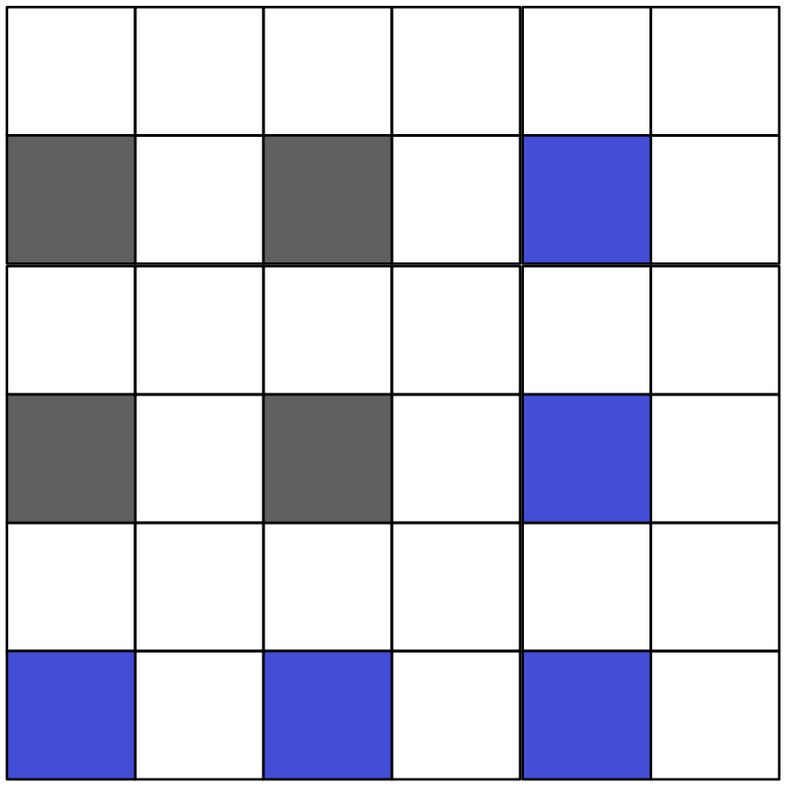




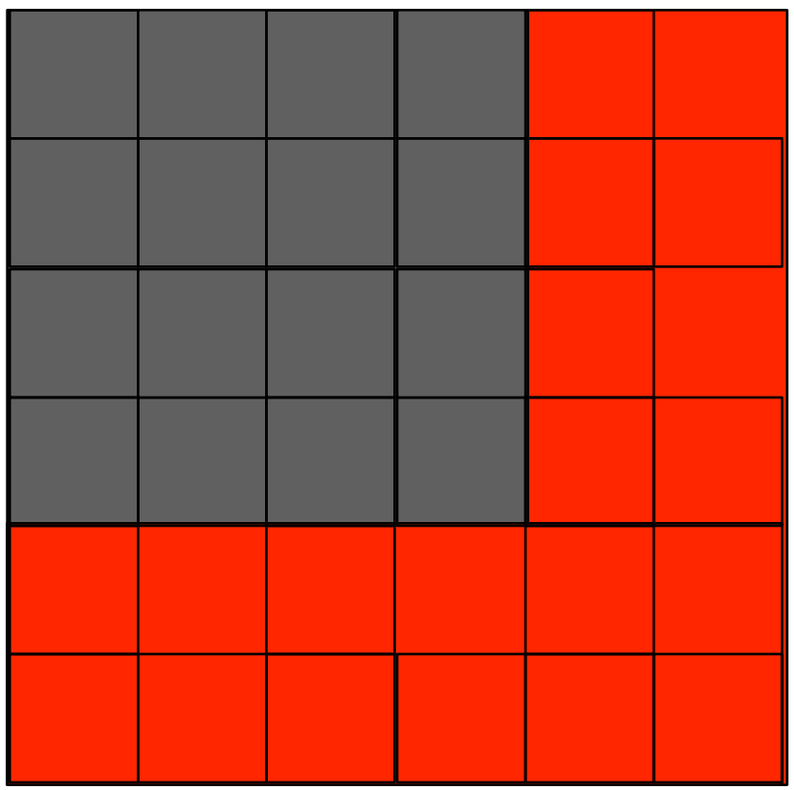
Add back green

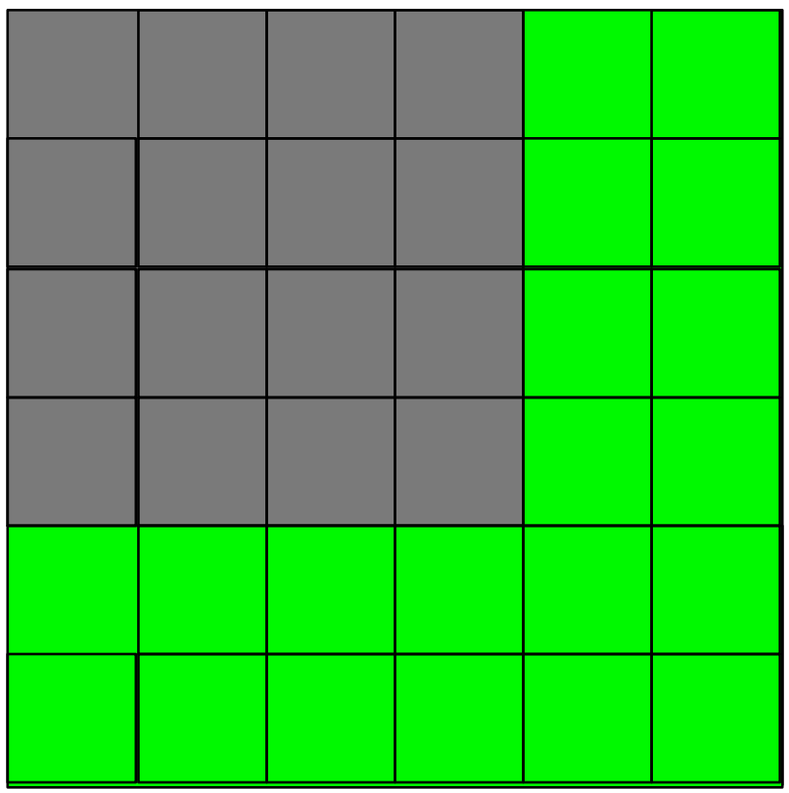


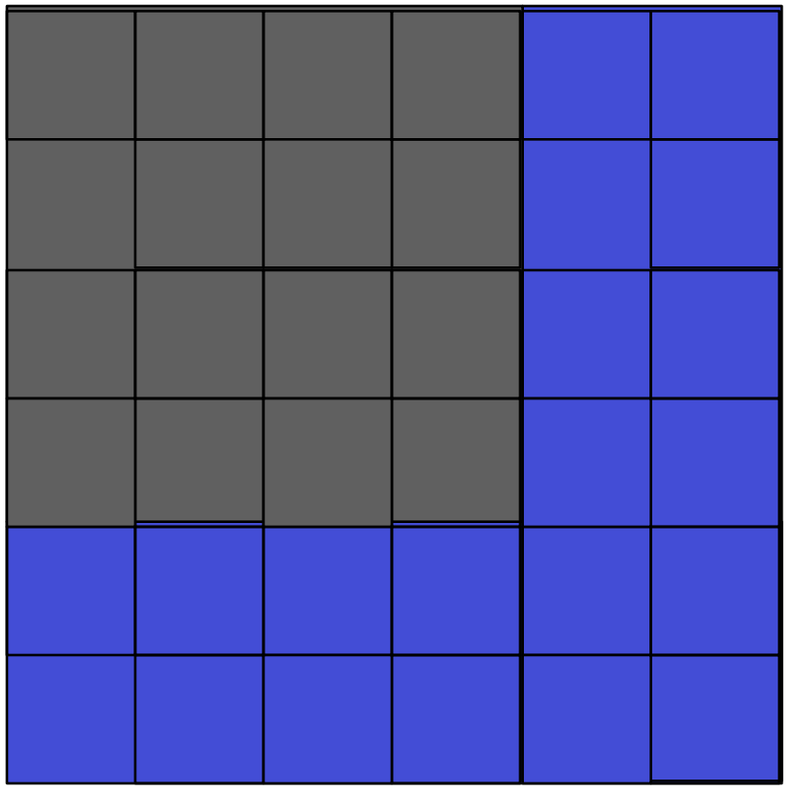




Same for blue







slide by Frédo Du

Fully naive

slide by Frédo Dura

Edge-based green, naive red blue

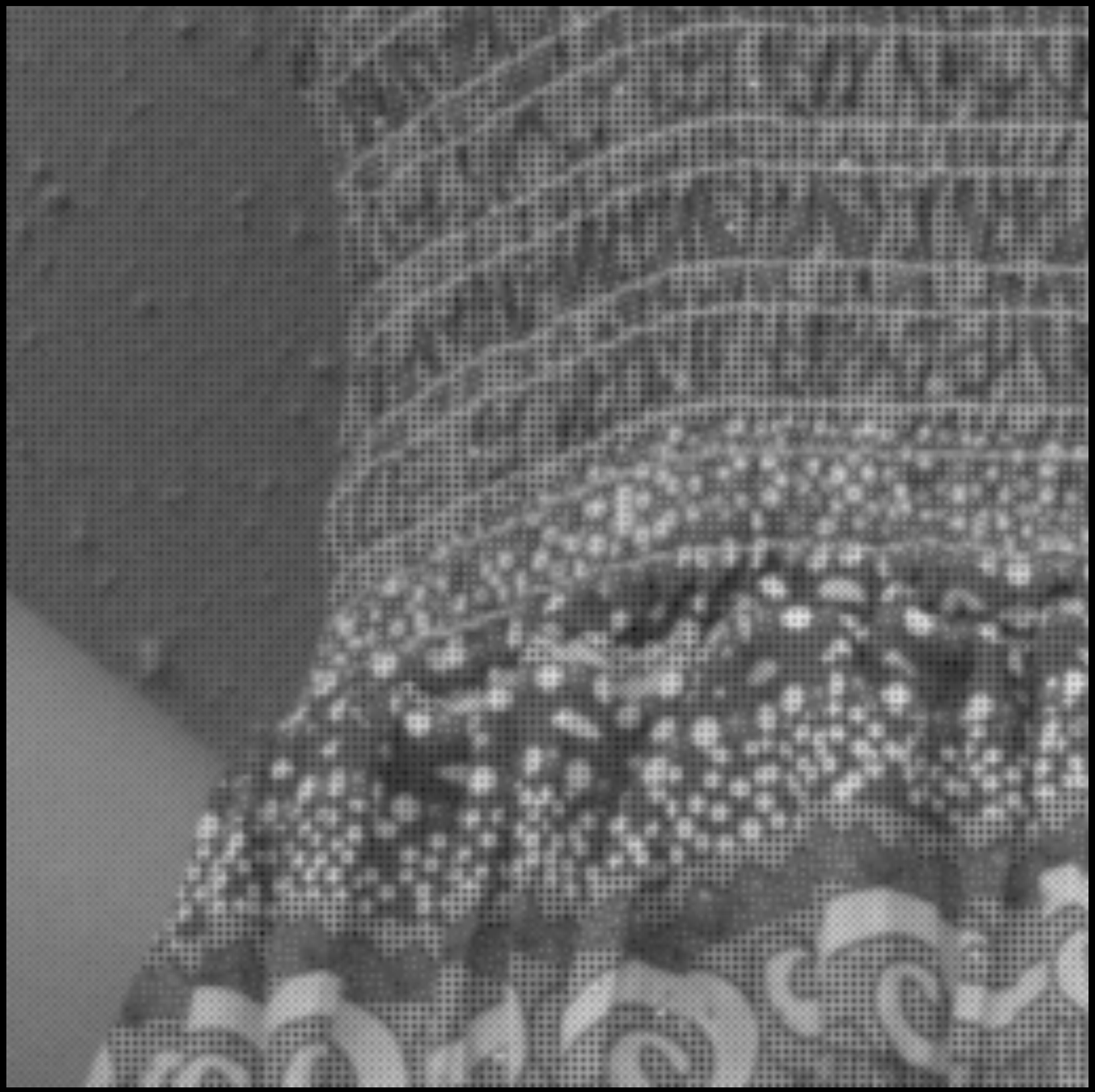
slide by Frédo Durand, MIT

Green-based blue and red

slide by Frédo Durand, MIT

Still not 100% perfect

- But will be good enough for pset 4



bayer

block

centered

naïve full-res

edge-based

dcraw

dcraw

bayer

dcraw

block

dcraw

centered

dcraw

naïve full-res

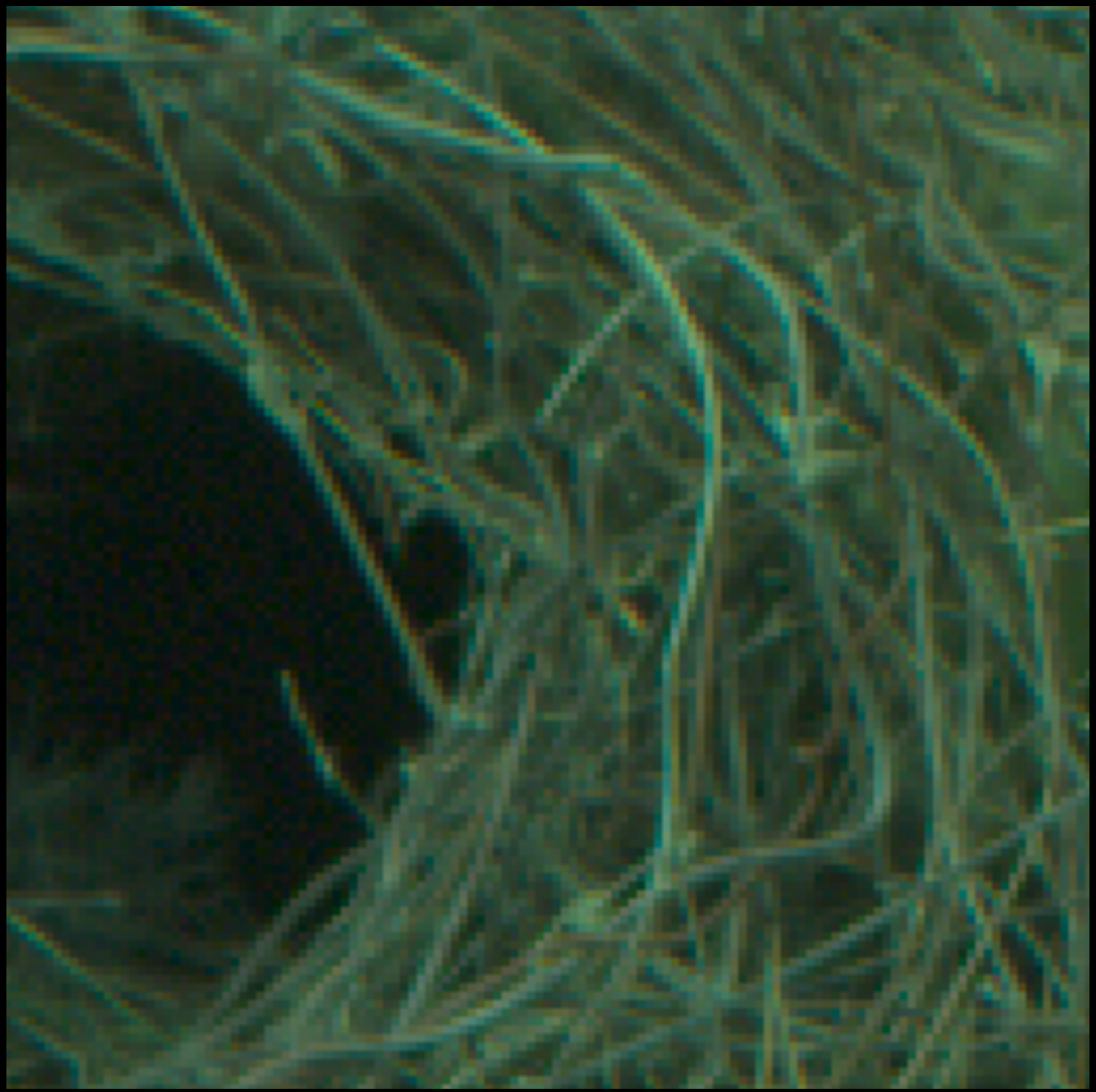
dcraw

edge-based

dcraw

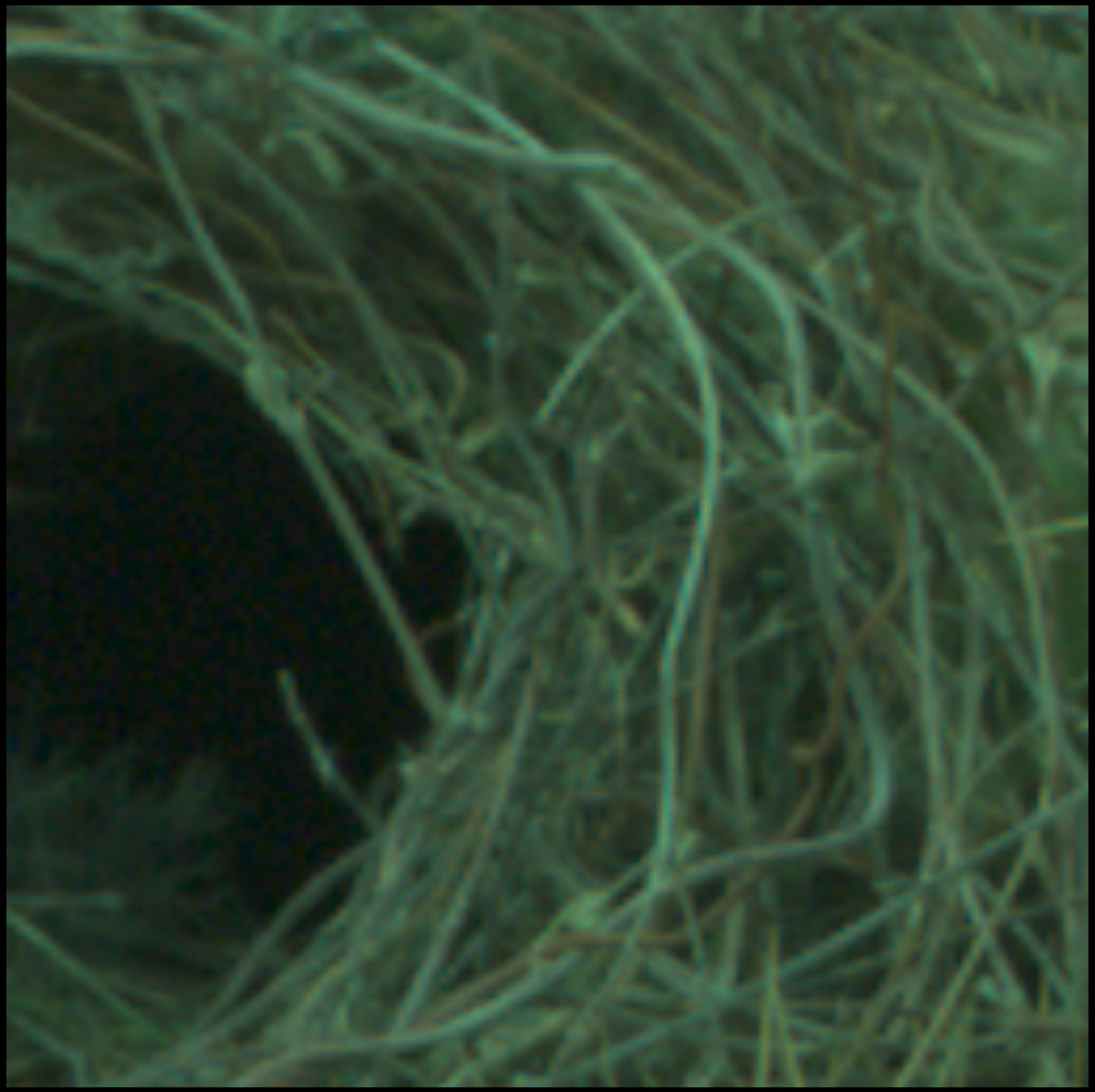
dcraw

bayer



block

centered



naïve full-res

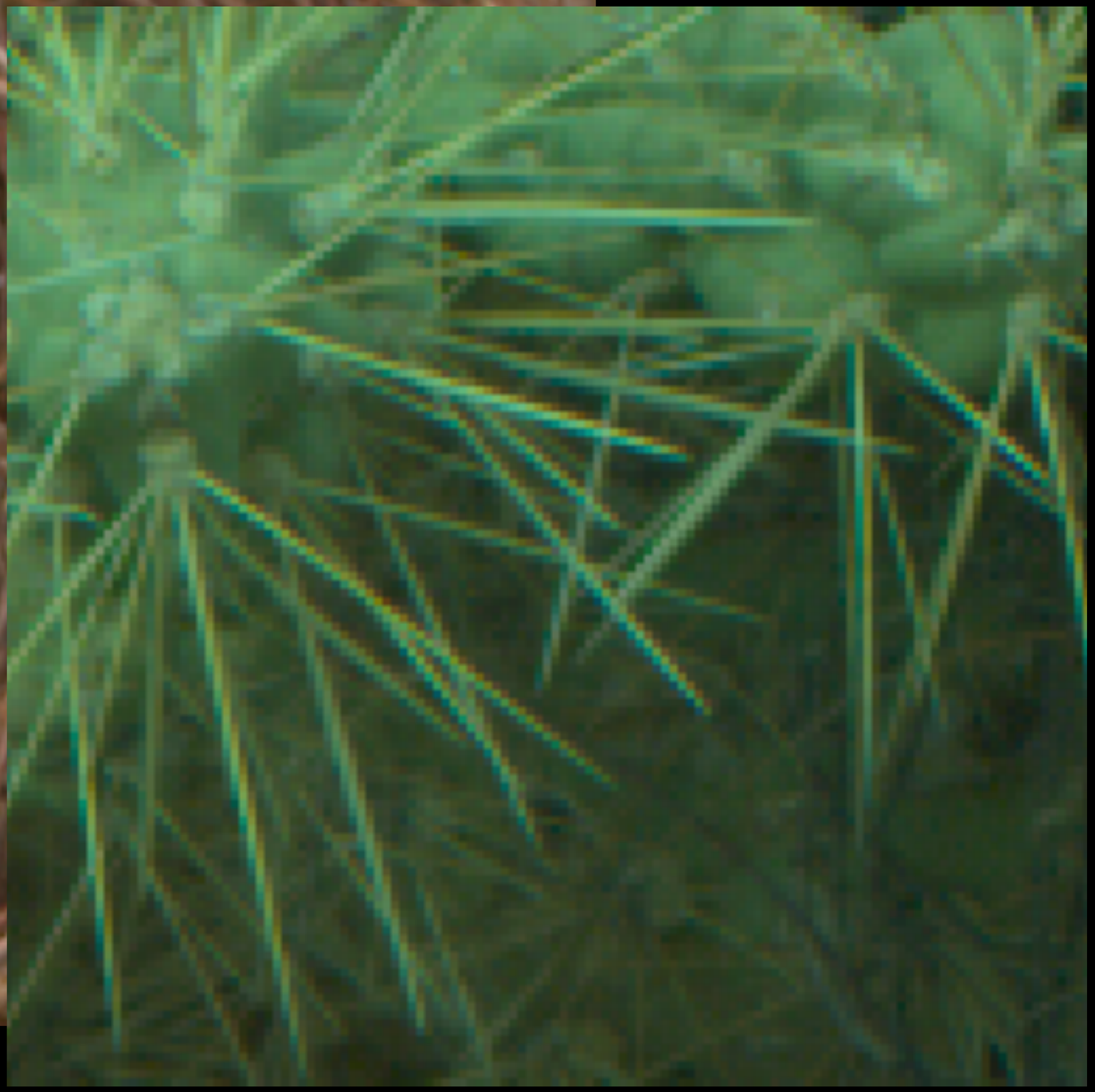
edge-based

dcraw

dcraw

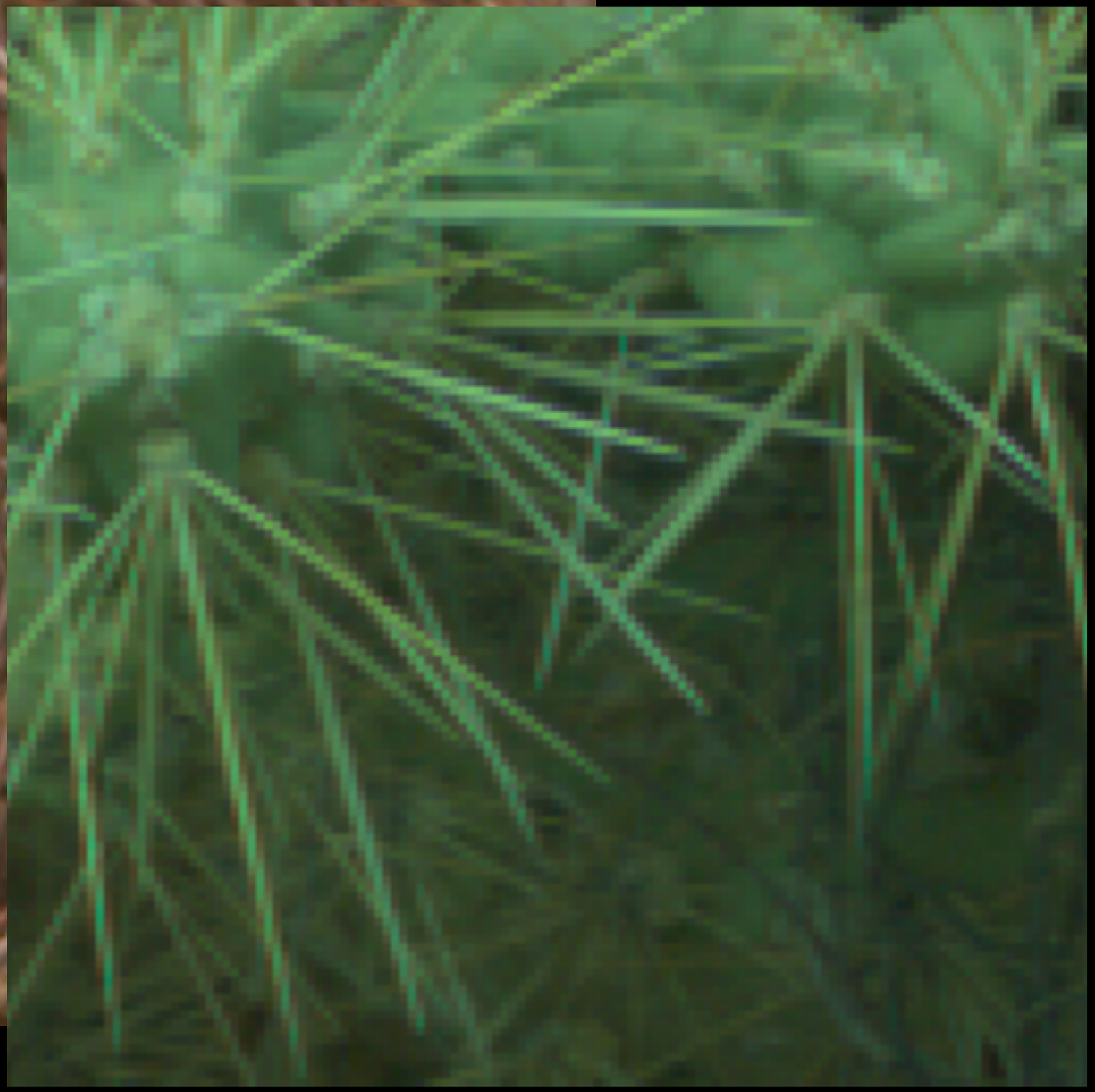
bayer

dcraw



block

dcraw



centered

dcraw

naïve full-res

dcraw

edge-based

dcraw

dcraw

Noise reduction

- **Users want noise out of their images**

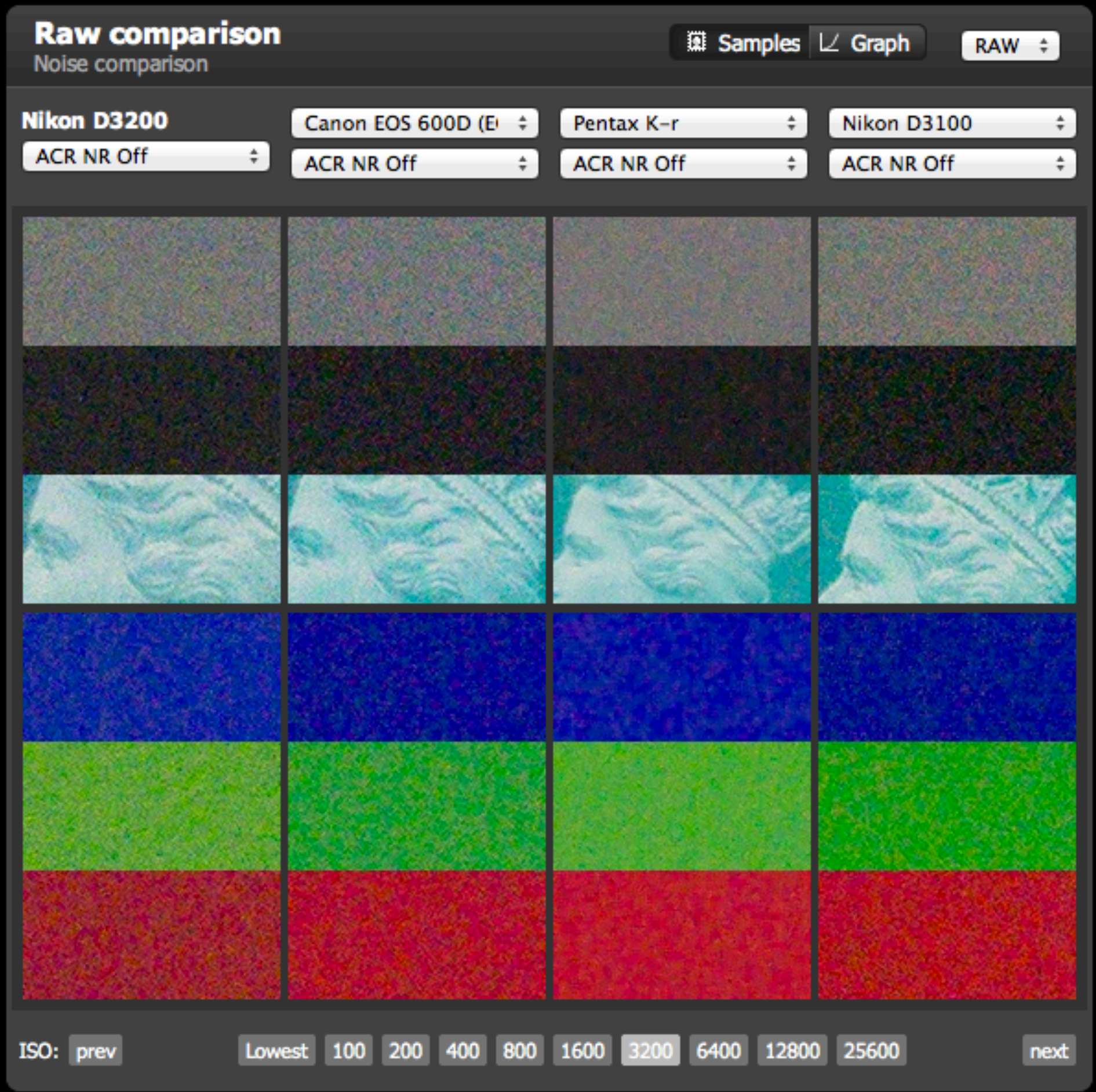
  shot noise increases as sqrt(exposure)
  relative shot noise decreases as sqrt(exposure)
  relative readout noise increases prop. to exposure
  higher ISO settings try to reduce relative readout noise

- **Basic approach: average together measurements**
- **Be clever, spatially, to avoid blurring image structure**
- **One approach: bilateral filter**

  more on this later

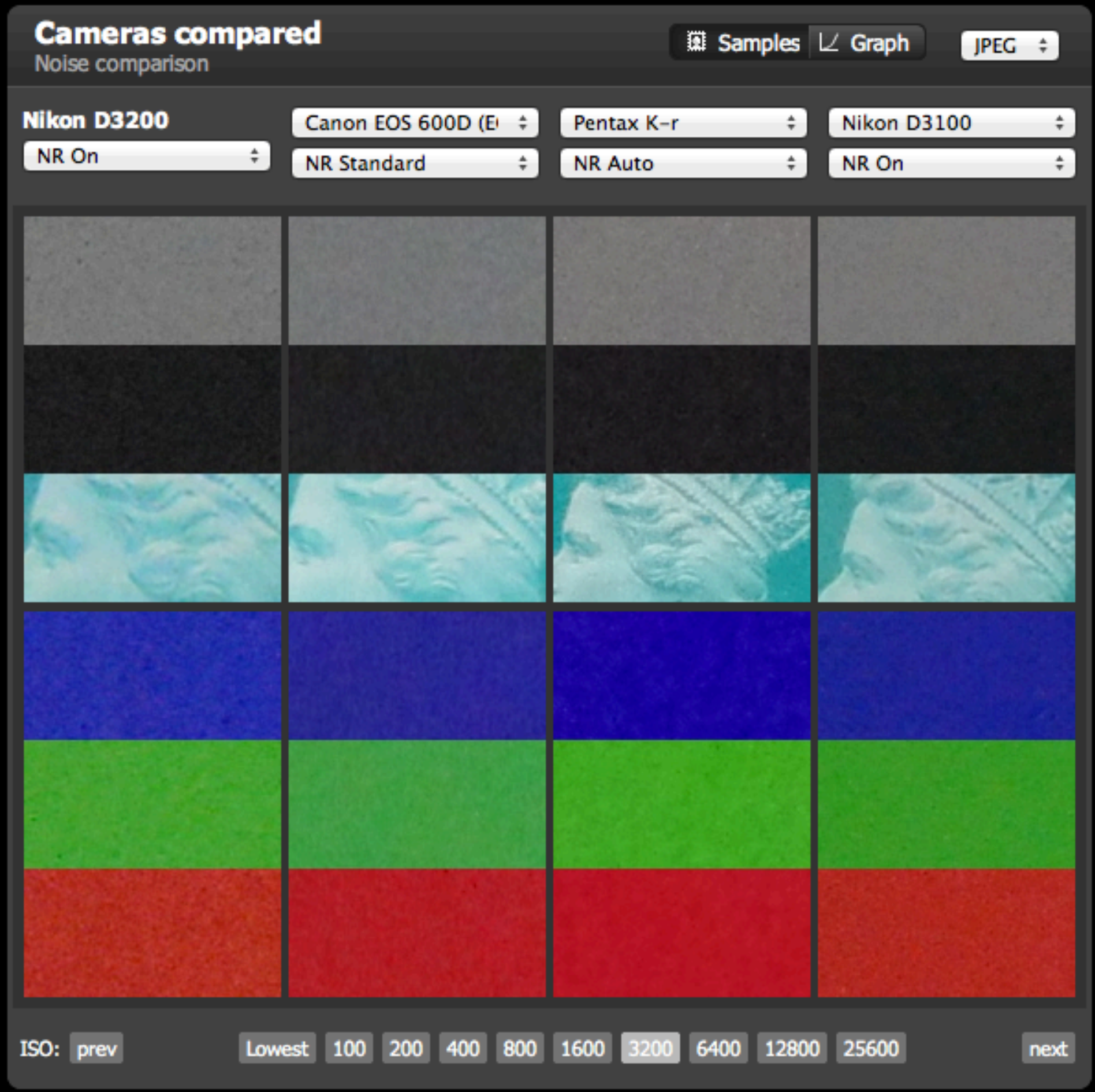
- **Camera makes all have their proprietary methods**

dpreview.com camera noise comparison tool



worth a look:
http://www.dpreview.com/reviews/nikon-d3200/12

dpreview.com camera noise comparison tool

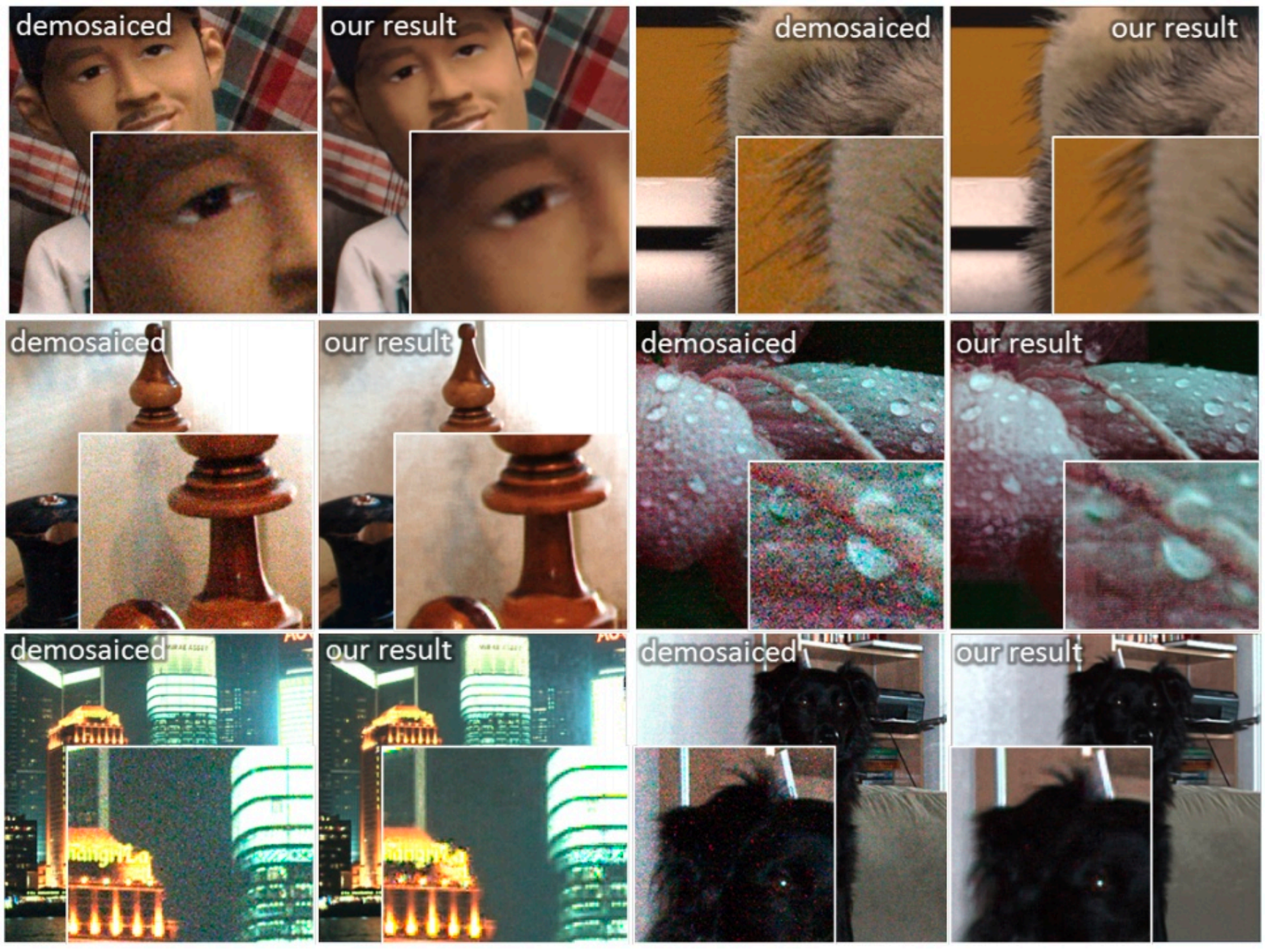


worth a look:
http://www.dpreview.com/reviews/nikon-d3200/12

slide by Frédo Durand, MIT

Denoising & Demosaicking

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



Camera processing pipeline

- **read image out from sensor** —see Sensors lecture
- **optional: HDR assembly** —see Homework 2
- **color balance** —see Color lecture
- **demosaic**
- **noise processing**
- **color matrix** —see Color lecture
- **tone map** —more on this in the project and papers

slide by Frédo Durand, MIT

Links from Frédo

- http://www.csee.wvu.edu/~xinl/papers/demosaicing_survey.pdf

- http://www.unc.edu/~rjean/demosaicing/demosaicing.pdf
- 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=14077&arSt=+44&ared=+54&arAuthor=Gunturk%2C+B.K.%3B+Glotzbach%2C+J.%3B+Altunbasak%2C+Y.%3B+Schafer%2C+R.W.%3B+Mersereau%2C+R.M.