Digital Image Processing Basics

George Legrady © 2022
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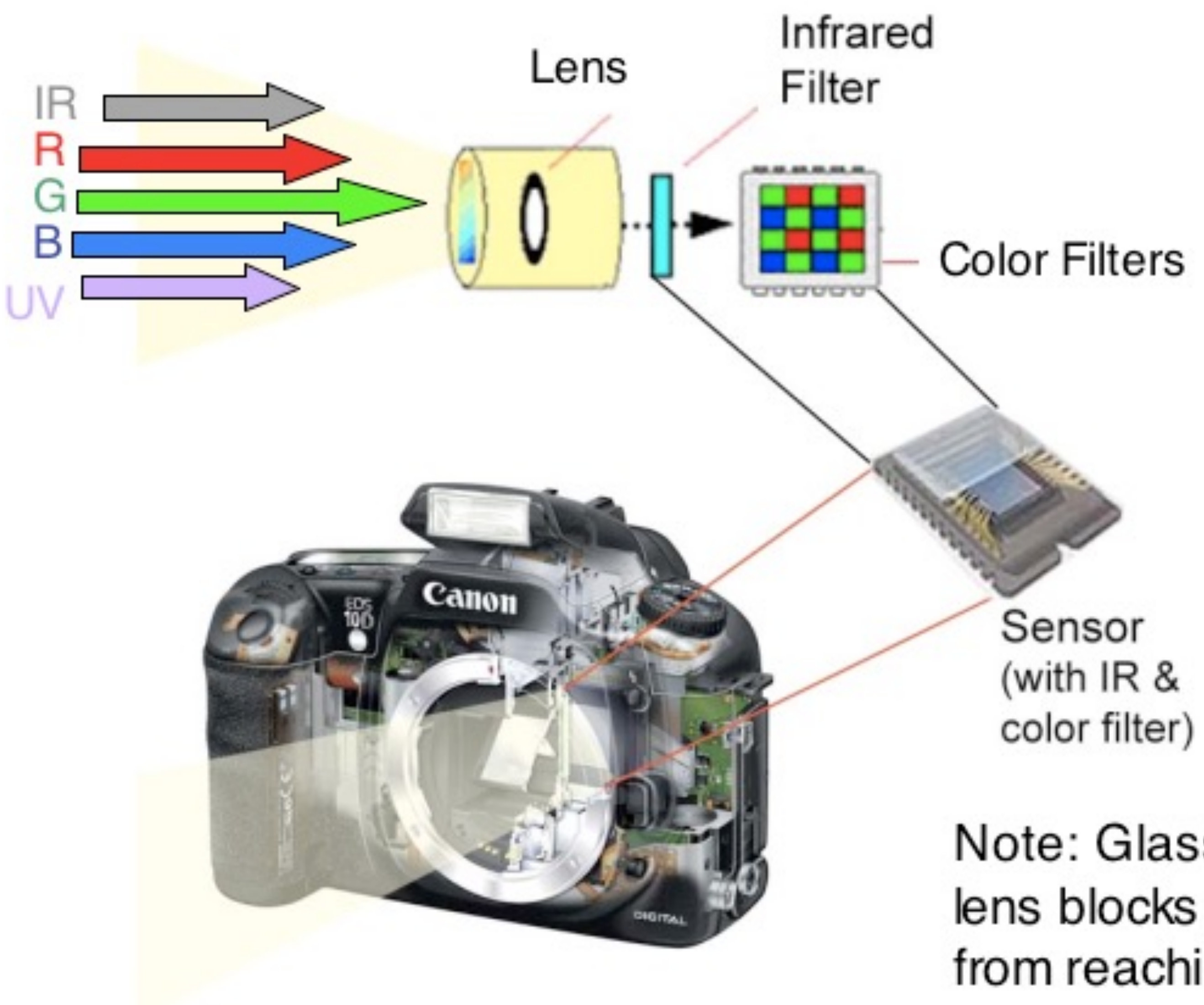
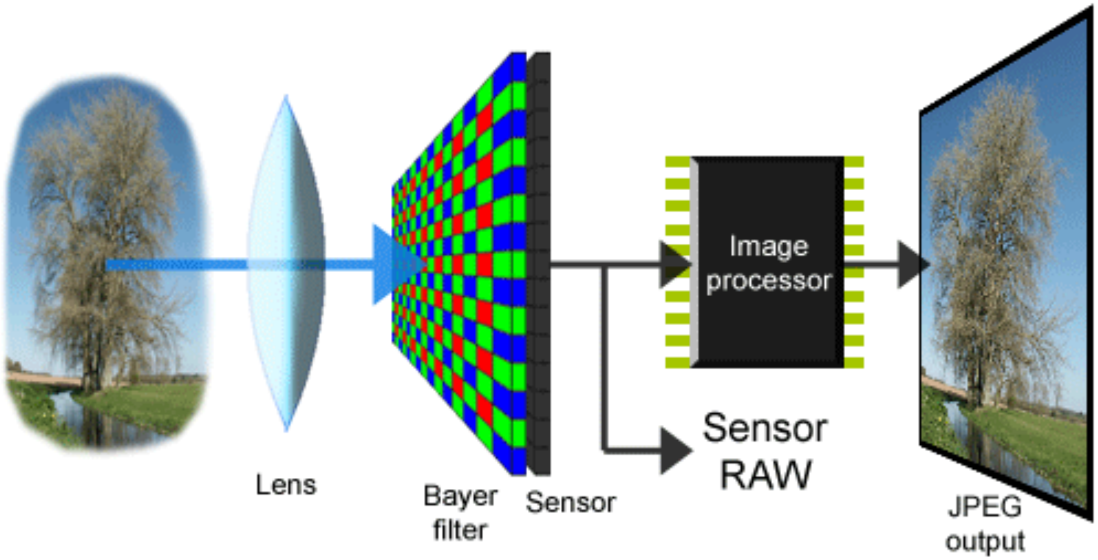
Inside the Digital Camera

How does it detect light?



Note: Glass in camera lens blocks most UV from reaching sensor

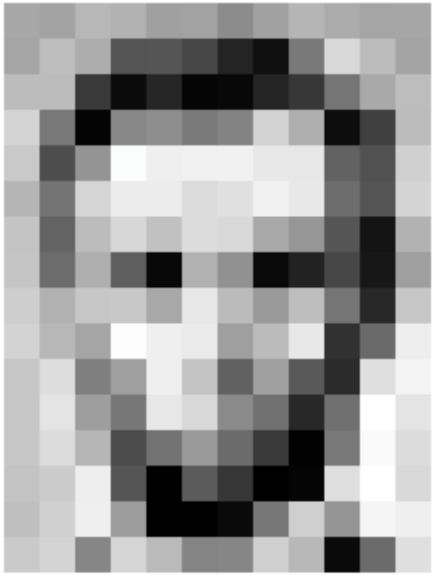
The Digital image as Signal

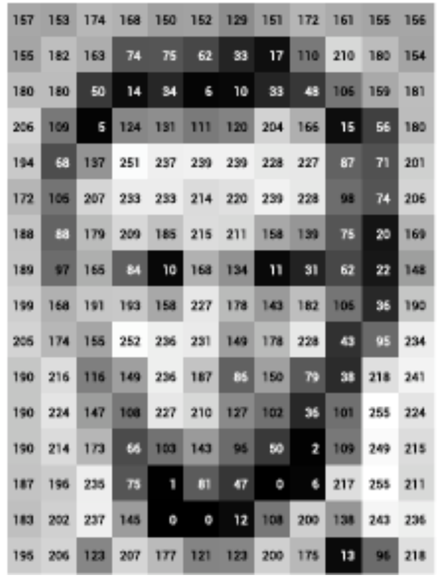


- Light captured by sensors in the camera is converted into digital form through sampling and quantization
- A signal is a mathematical function and conveys some information
- It can be processed mathematically through algorithms

(*An algorithm is a finite but repeatable sequence of computer-instructions, active until it reaches a pre-defined limit*)

Digital image *made up of pixels* is a multi-dimensional data structure





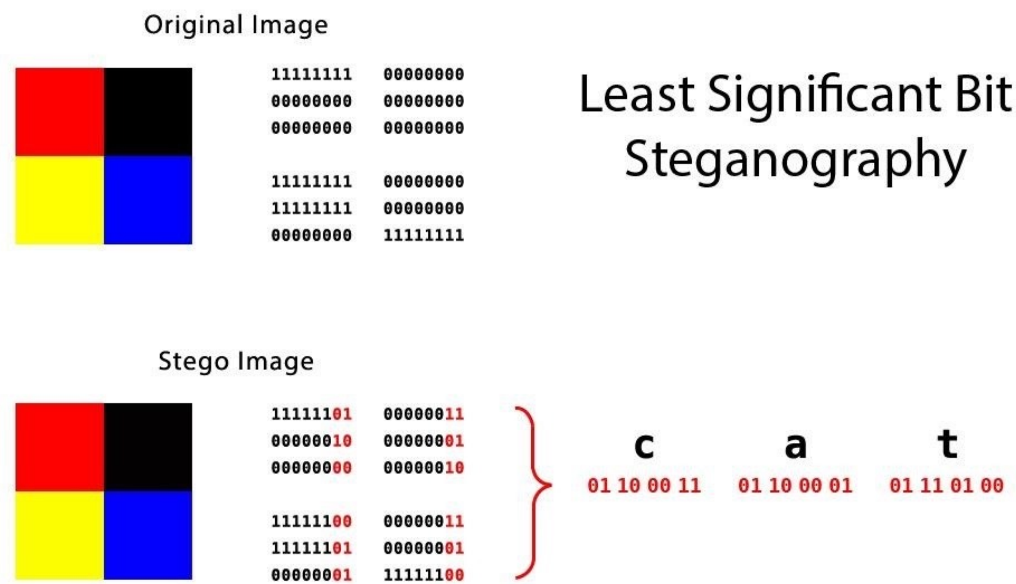
157	153	174	168	150	152	129	151	172	161	155	156
155	182	163	74	75	62	33	17	110	210	180	154
180	180	50	14	34	6	10	33	48	106	159	181
206	109	5	124	131	111	120	204	166	15	56	180
194	68	137	251	237	239	239	228	227	87	71	201
172	105	207	233	233	214	220	239	228	98	74	206
188	88	179	209	185	215	211	158	139	75	20	169
189	97	165	84	10	168	134	11	31	62	22	148
199	168	191	193	158	227	178	143	182	106	36	190
205	174	155	252	236	231	149	178	228	43	95	234
190	216	116	149	236	187	86	150	79	38	218	241
190	224	147	108	227	210	127	102	36	101	255	224
190	214	173	66	103	143	96	50	2	109	249	215
187	196	235	75	1	81	47	0	6	217	255	211
183	202	237	145	0	0	12	108	200	138	243	236
195	206	123	207	177	121	123	200	175	13	96	218

- Pixel ***Horizontal*** location
- Pixel ***Vertical*** location
- Pixel ***Red*** color value
- Pixel ***Green*** color value
- Pixel ***Blue*** color value
- Pixel ***Alpha*** (transparency) value
- The whole image has a ***BitDepth*** resolution (2bit, 8bit, etc.)

Digital image *made up of pixels* is a multi-dimensional data structure

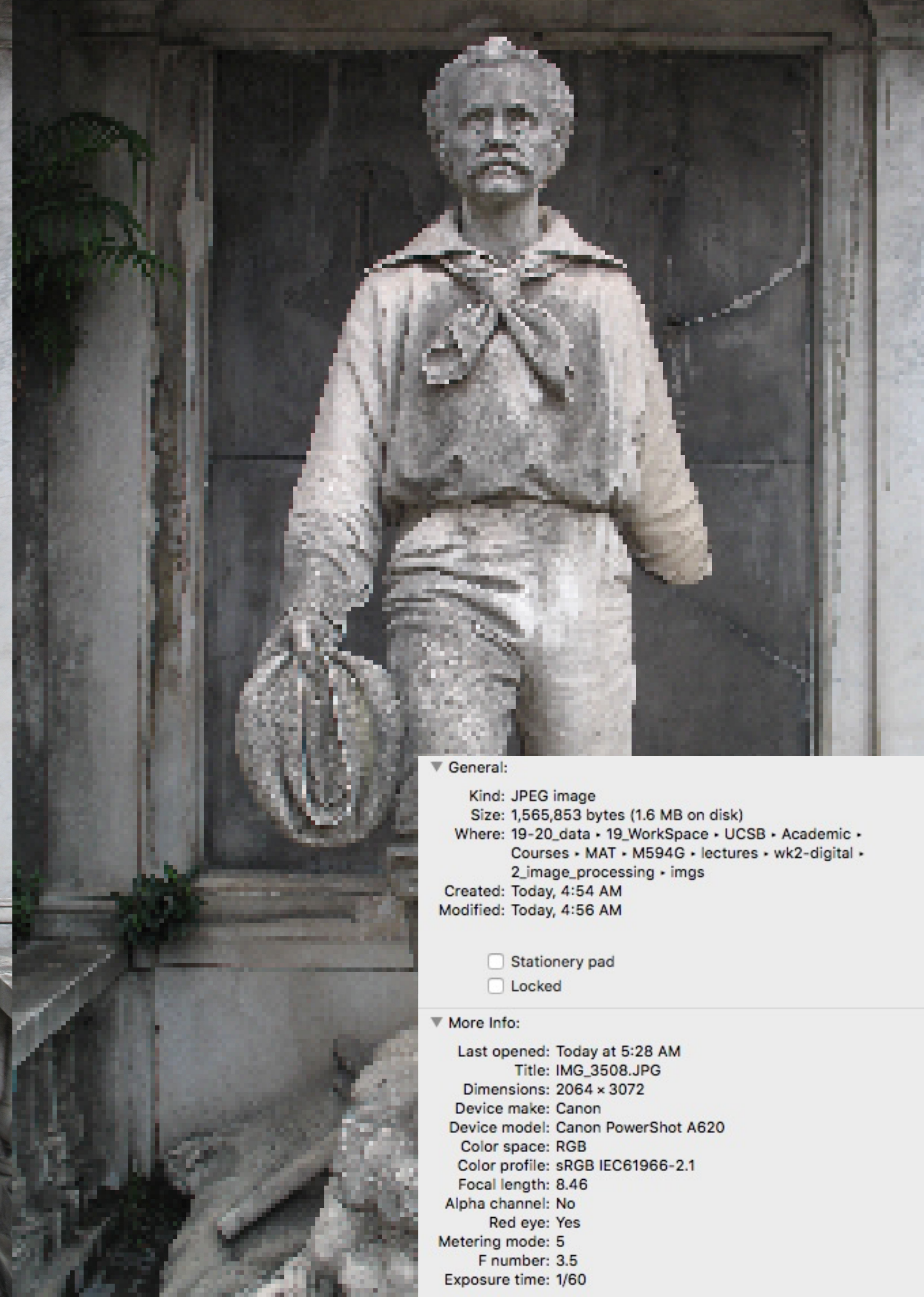
- *Pixel **Horizontal*** location: **2560**
- Pixel ***Vertical*** location: **1920**
- **Each pixel has R,G,B values between 0 to 255**
- **Total bytes: 1,678,364 (1.7MB, JEPG result)**

Steganography: Compression allows for hiding data inside an image



- Steganography is the concealment of information within computer files
- When images are compressed, for instance if adjoining pixels have the same colors, this can be stored in shorthand as “3 x 245,23,67”, instead of “245,23,67”, “245,23,67”, “245,23,67” saving space
- Free space can be used to store other data which is then hidden

EXIF Data (*Digital cameras embed into the image how it was created*)



Sampling at different resolutions – DPI resolution (Dots per inch)

1.6 MB (100 dpi)

950 KB (10 dpi)

Two examples of different resolutions: grey scale (left), 2 bit dither (right)

“jpeg ny02”, Thomas Ruff (2004)

https://www.davidzwirner.com/artists/thomas-ruff/survey#/jpeg-ny02--artwork-77CD3288-624F-46D1-8082-6DF161AEBBE0/Artwork

Lossy JPEG Compression

- In information technology, **lossy compression** or **irreversible compression** is the class of data encoding methods that uses inexact approximations and partial data discarding to represent the content. These techniques are used to reduce data size for storing, handling, and transmitting content.

- This is opposed to lossless data compression (reversible data compression) which does not degrade the data. The amount of data reduction possible using lossy compression is much higher than through lossless techniques.

- Lossy compression is most commonly used to compress multimedia data (audio, video, and images), especially in applications such as streaming media and internet telephony. By contrast, lossless compression is typically required for text and data files, such as bank records and text articles.

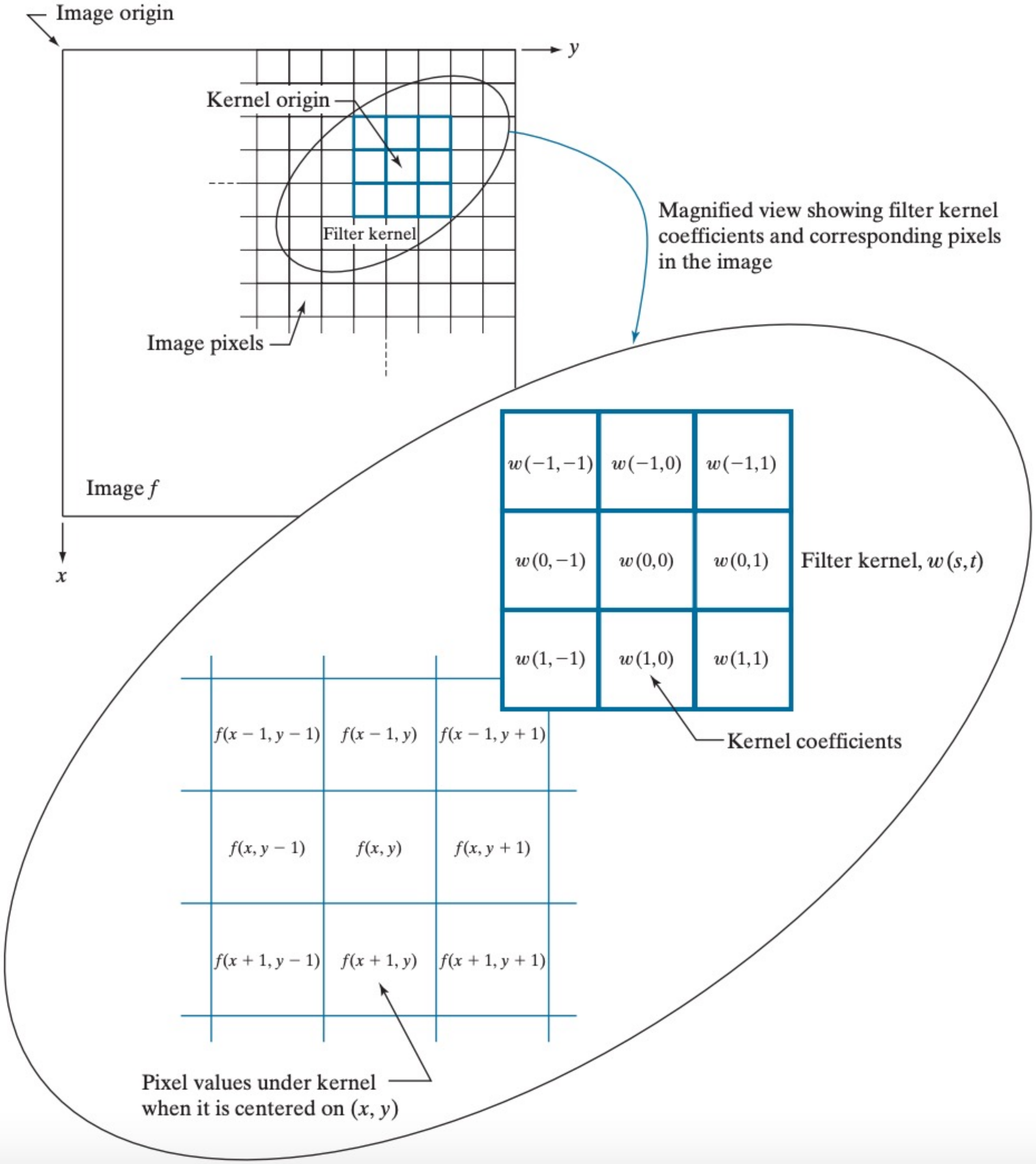
Some Image Processing Functions

- Sharpen
- Blur
- Detect edges

- Adjust color balance
- Adjust contrast
- Add/remove noise

Linear Spatial Filtering

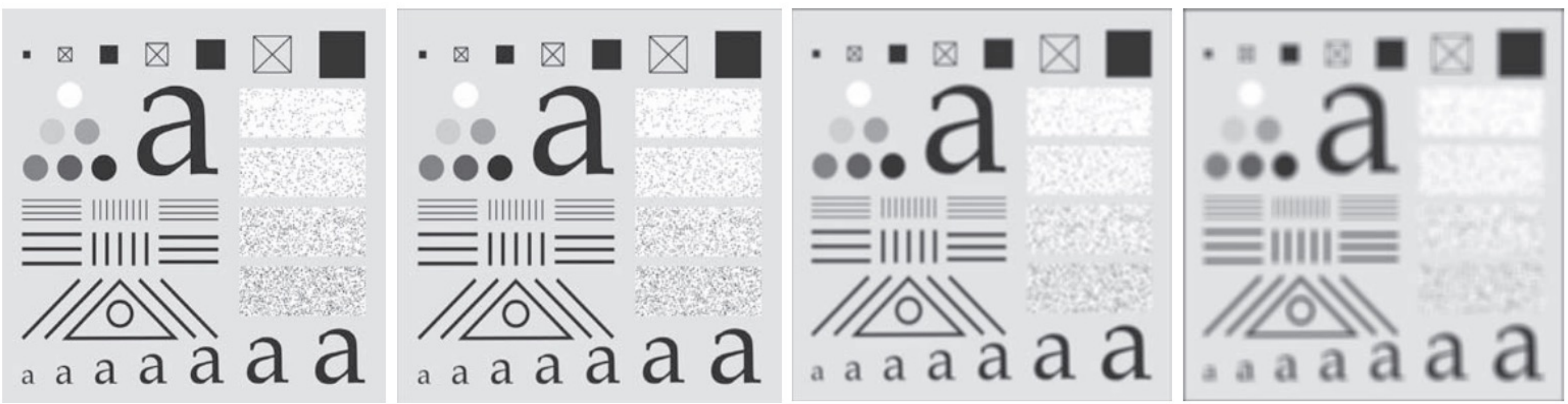
FIGURE 3.28 The mechanics of linear spatial filtering using a 3×3 kernel. The pixels are shown as squares to simplify the graphics. Note that the origin of the image is at the top left, but the origin of the kernel is at its center. Placing the origin at the center of spatially symmetric kernels simplifies writing expressions for linear filtering.



Blurring (Smoothing)

- Replacing the center pixel with the mean of each pixel in the neighborhood to reduce sharp grayscale changes

$$\frac{1}{9} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \qquad \frac{1}{16} \times \begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

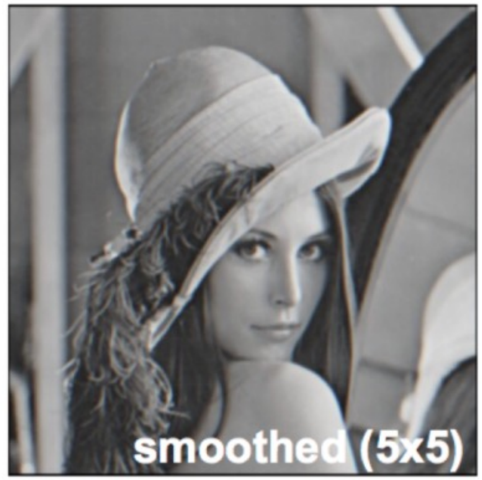


Original   Size 3*3   Size 11*11   Size 21*21

Sharpening

- Step 1: Original - Smoothed = "Details"

–



=

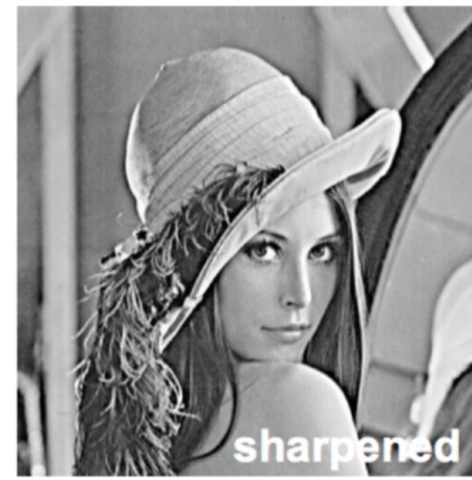
$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} - \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Sharpening

- Step 2: Original + "Details" = Sharpened

+ a

=



$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} - \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 0 \end{bmatrix} - \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Edge Detection

- Edge: pixels where the grey scale changes rapidly
- How to calculate the changing speed?
  - Derivative
    - First Order: $\frac{\partial \mathrm{f}}{\partial \mathrm{x}} = f(x+1) - f(x)$
    - Second Order : $\frac{\partial^2 f}{\partial x^2} = \frac{\partial f\prime}{\partial \mathrm{x}} = f(x+1) + f(x-1) - 2f(x)$
    - For Second Order Derivative in 2D image:
      - Horizontally: $\frac{\partial^2 f}{\partial x^2} = f(x+1, y) + f(x-1, y) - 2f(x, y)$
      - Vertically: $\frac{\partial^2 f}{\partial y^2} = f(x, y+1) + f(x, y-1) - 2f(x, y)$
      - Add Up: $\nabla^2 f(x, y) = f(x+1, y) + f(x-1, y) + f(x, y+1) + f(x, y-1) - 4f(x, y)$
      - Laplacian Kernel

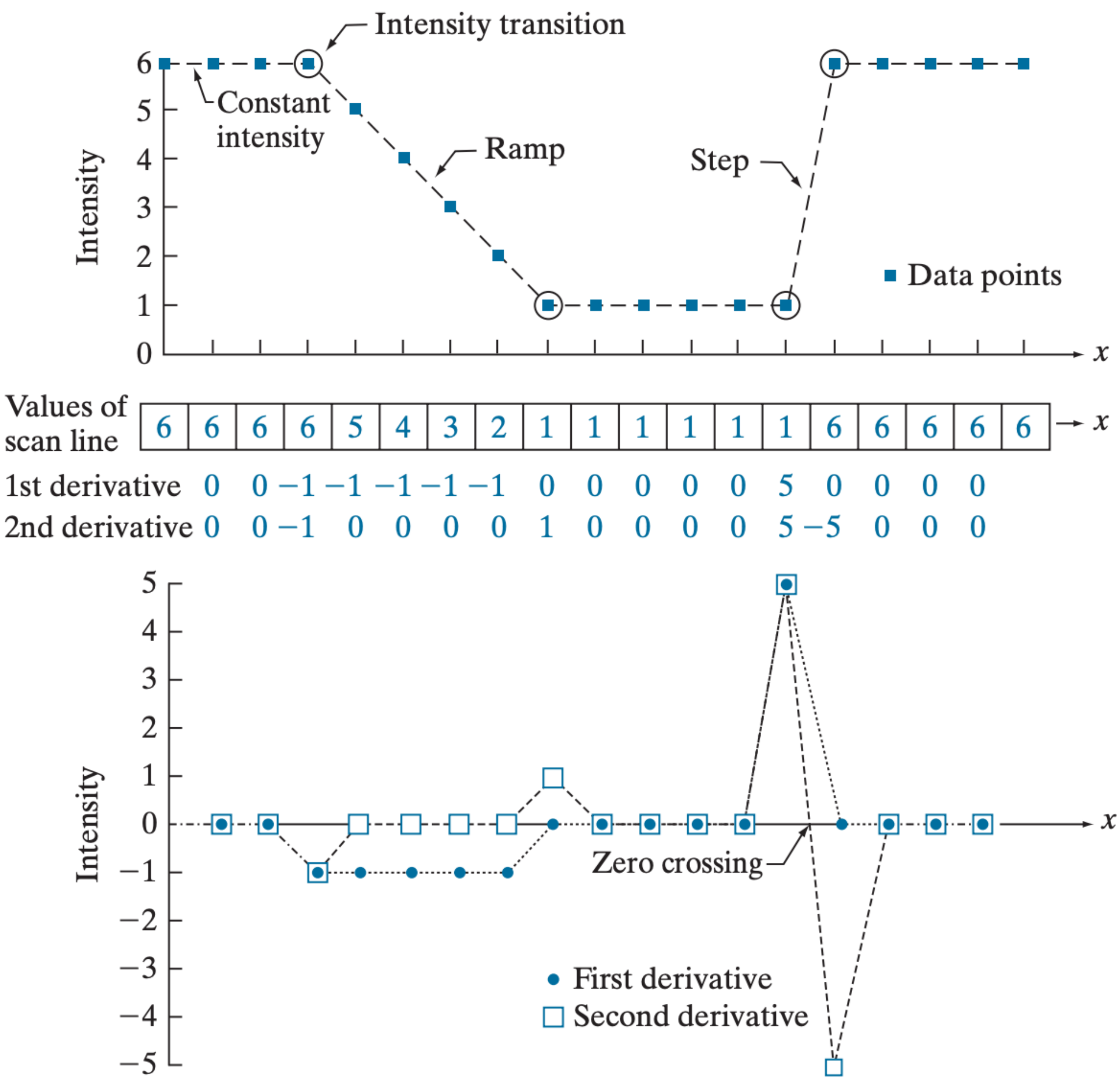
0	1	0
1	−4	1
0	1	0

1	1	1
1	−8	1
1	1	1

0	−1	0
−1	4	−1
0	−1	0

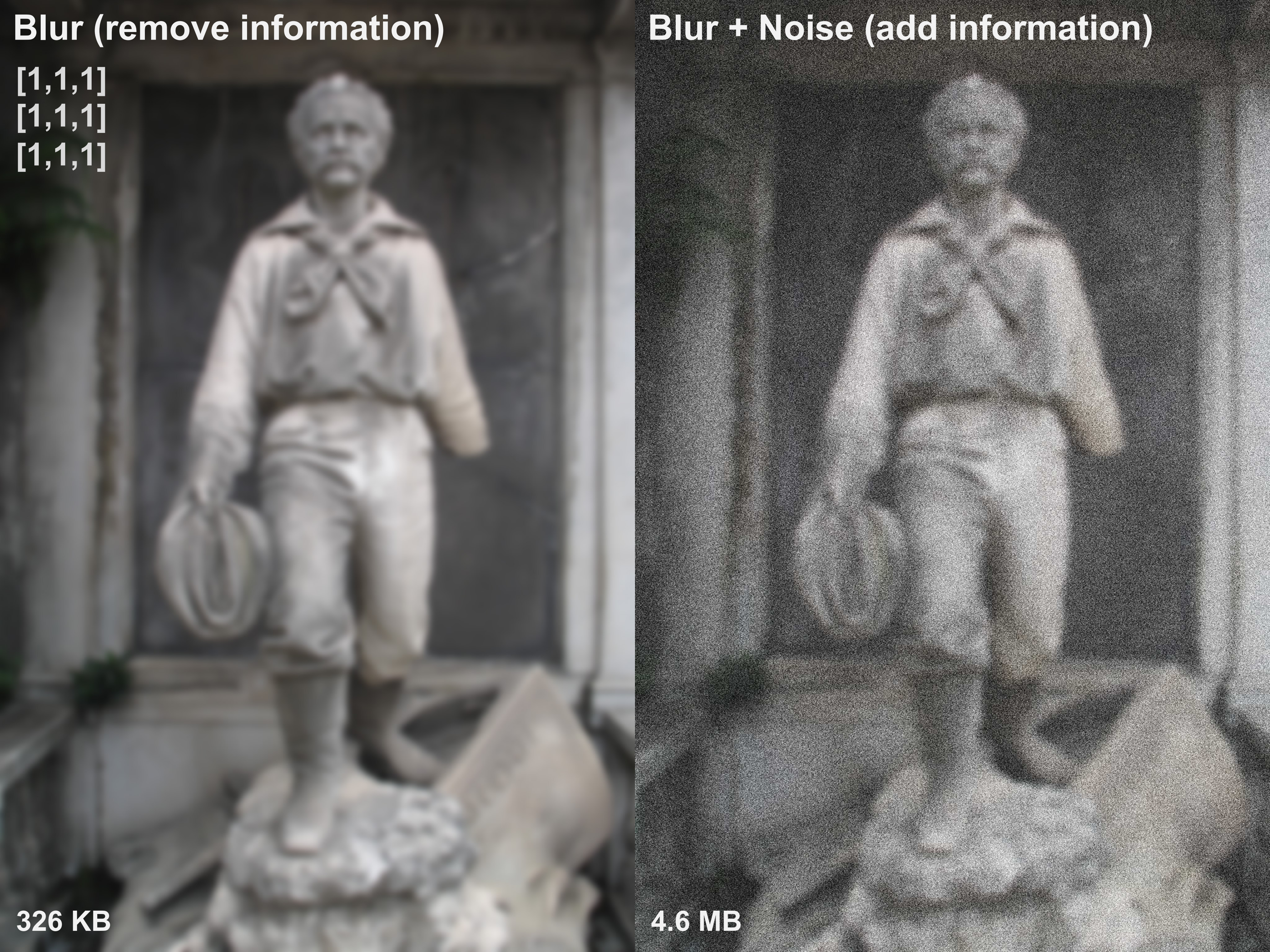
−1	−1	−1
−1	8	−1
−1	−1	−1

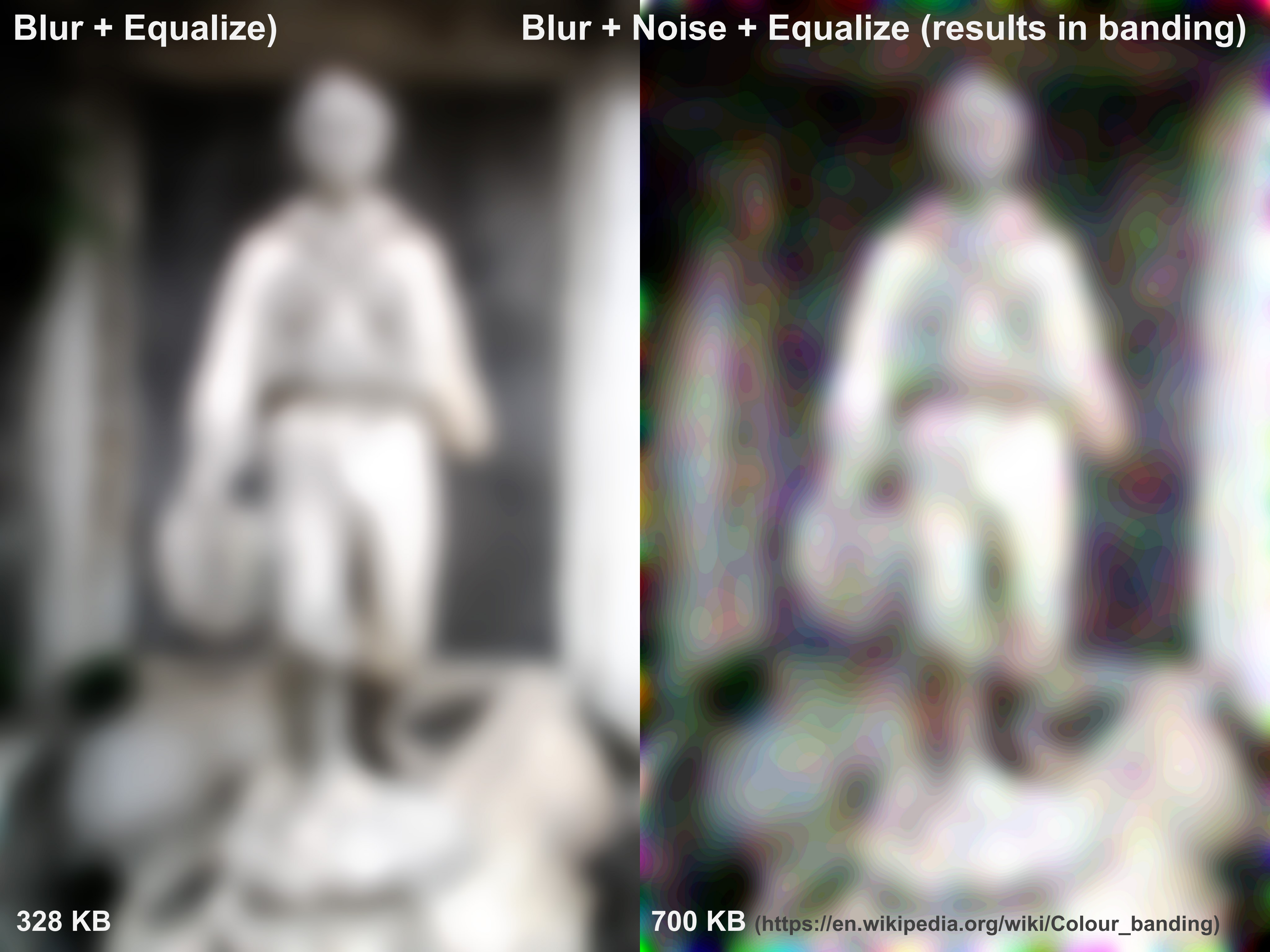
Edge Detection

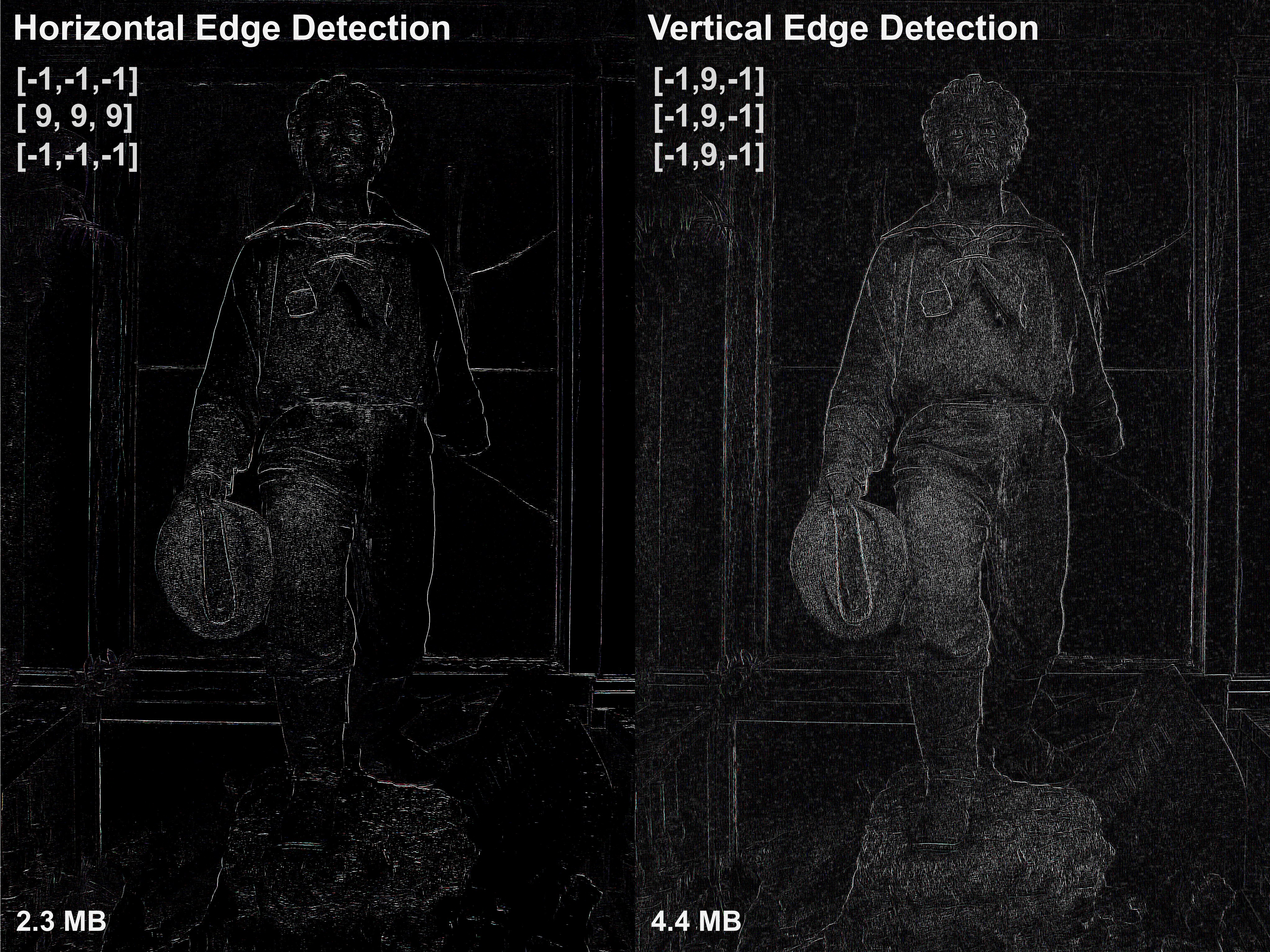



Sharpen
[1,1,1]
[1,9,1]
[1,1,1]
1.6 MB


Maximum Saturation
4.9 MB


Blur (remove information)
[1,1,1]
[1,1,1]
[1,1,1]
326 KB
Blur + Noise (add information)
4.6 MB


Blur + Equalize)
Blur + Noise + Equalize (results in banding)
328 KB
700 KB (https://en.wikipedia.org/wiki/Colour_banding)


Horizontal Edge Detection
[-1,-1,-1]
[9, 9, 9]
[-1,-1,-1]
2.3 MB
Vertical Edge Detection
[-1,9,-1]
[-1,9,-1]
[-1,9,-1]
4.4 MB

Brig on the Water, Gustave Le Gray (1856) – two negatives exposed

https://artmuseum.princeton.edu/collections/objects/15941

Ansel Adams Zone System developed in collaboration with Fred Archer

1	2	3	4	5	6	7	8	9

Zone system chart for gamma = 2.2 (PC's, sRGB color space)>

Zone system chart for gamma = 1.8 (Macintosh)

Note 1. To display these tables correctly in Netscape, the Always use my colors, overriding document box must be unchecked. Click Edit, Preferences, Appearance, Colors) In Firefox, click Tools, Options, General, Fonts & Colors. To print in Internet Explorer 5, Click on Tools, Internet Options..., Advanced. Scroll down and check the box, "Print background colors and images." You might want to uncheck it afterwards.

Note 2. The best way to print these charts, which are HTML tables, ***not*** image files, is the following. (1) Adjust the width of the window for proportions you like. (2) Copy the window into the clipboard by pressing Ctrl-PrintScreen on your keyboard. (3) Paste the image into your image editor. (4) Crop it and otherwise adjust it in the editor. (5) Print it from the editor.

High-Dynamic Range: Emulating the Human Vision System

2 ev

0 ev

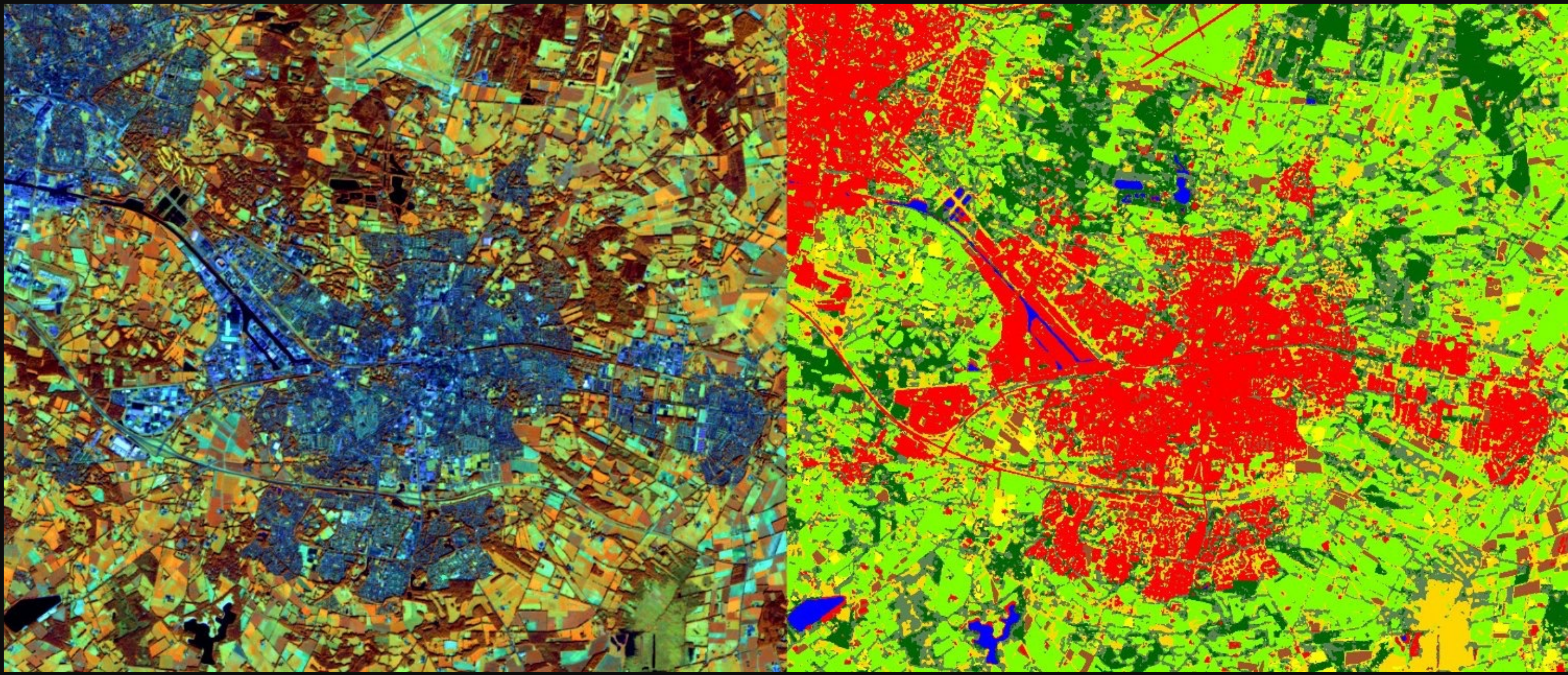
-2 ev

Tone-mapped HDR

Final image after post-processing

http://pristinekk.blogspot.com/2016/02/hdr-high-dynamic-range-hdr-photo-is.html

Remote Sensing & Digital Image Processing



https://www.itc.nl/education/studyfinder/remote-sensing-and-digital-image-processing/

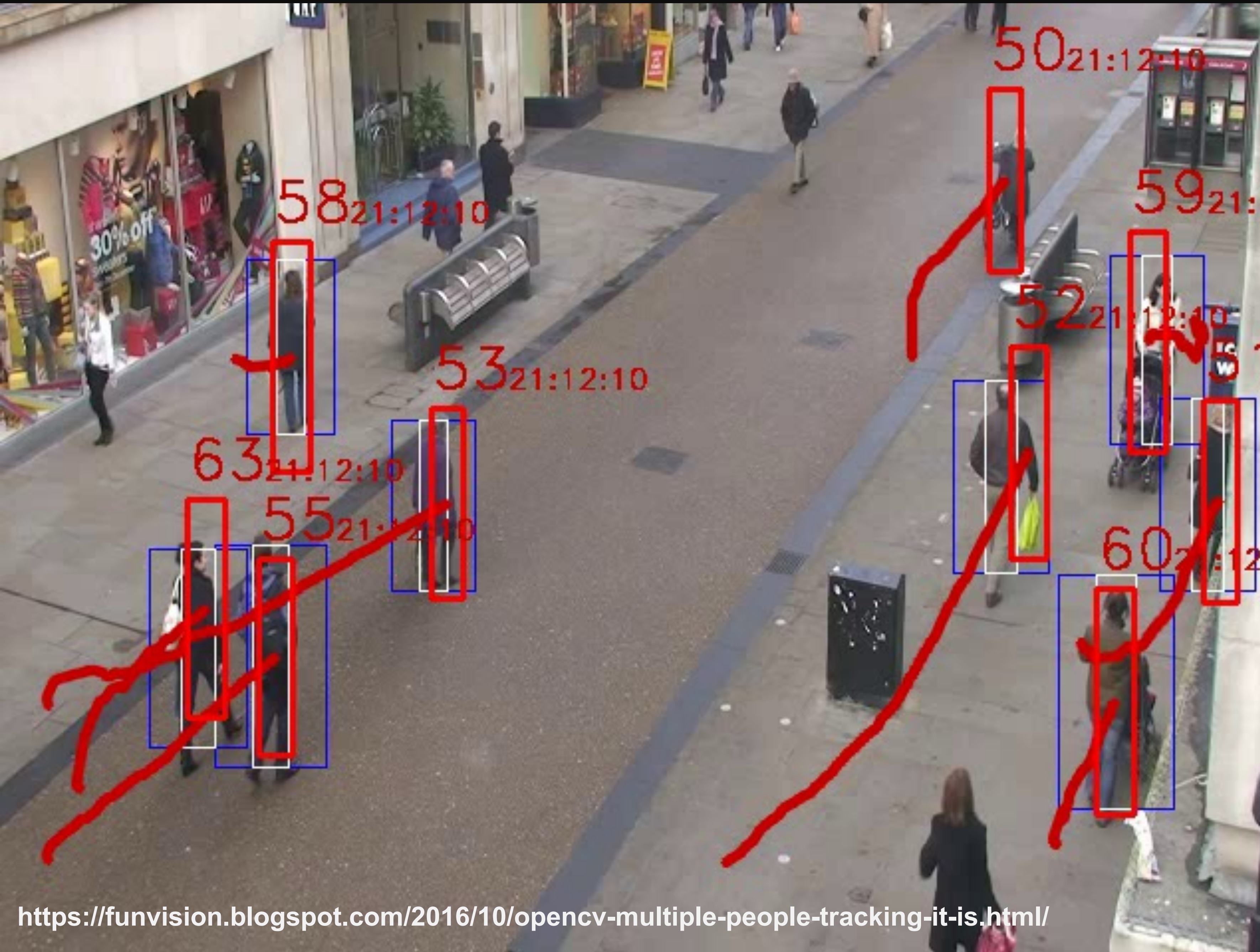
Aesthetic Primitives of Images for Visualization

Category	Primitives	Techniques to evaluate or to achieve
Color	Only a few strong colors.	
	Complementary contrast.	
	Exploitation of the dynamic range.	
Form	Clarity of form.	
	Silhouettes.	
Spatial organization	Clarity of spatial organization.	
	Golden mean	
	Texture and pattern.	
	Rhythm, repetition, and variation.	
Motion	Blur.	
	Distinct motion phases.	
Depth	Linear perspective.	
	Sharpness and unsharpness.	
	Light and shadow.	
Human body	Principal axes.	

Some Computer Vision Functions

- **Object Detection**: Identify contours to locate objects
- **Pattern Recognition**: Assigning labels to identified objects (car, flower, etc.)
- **Motion Tracking**: Subtract one image from another to identify change

Motion Tracking

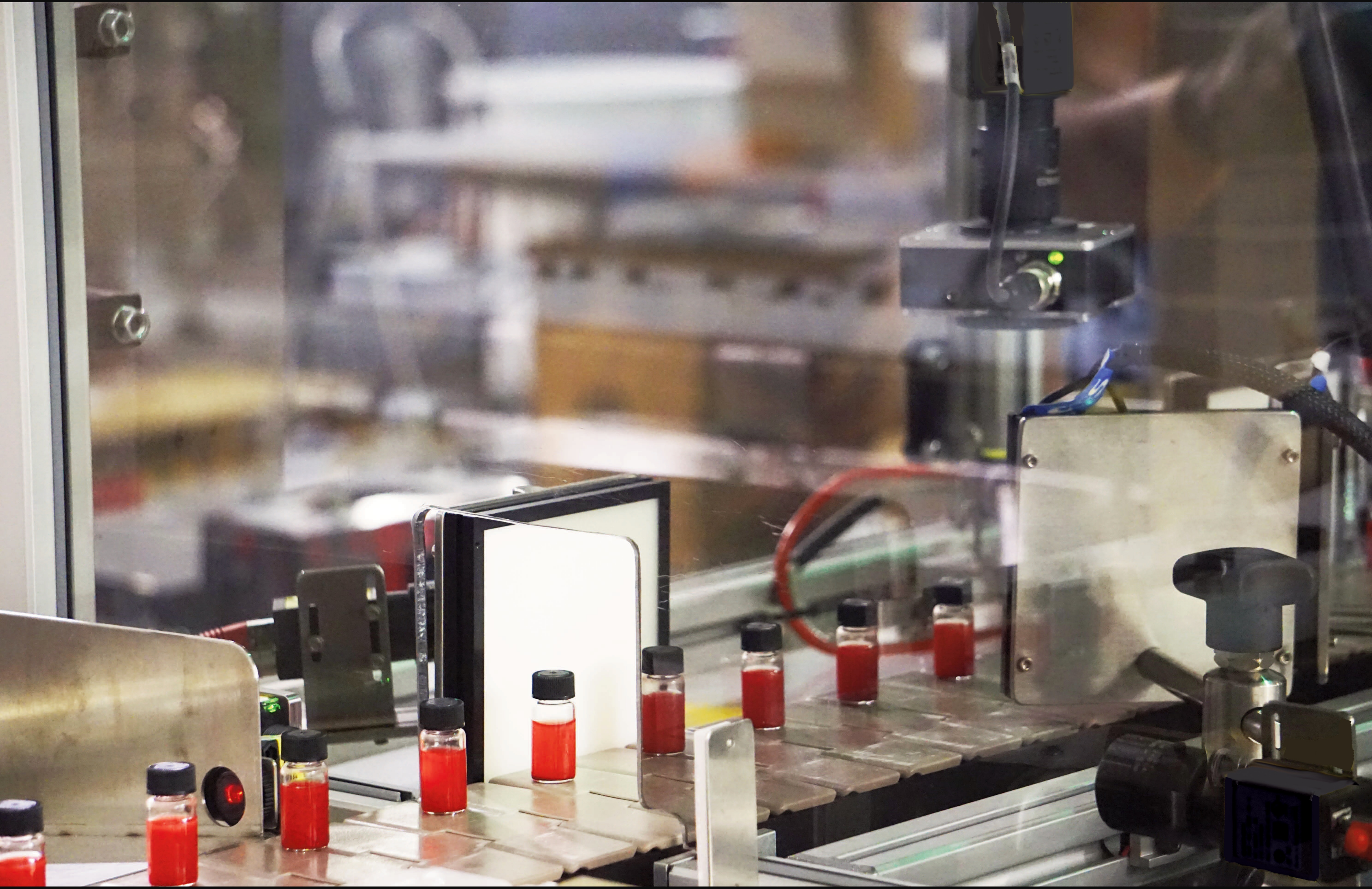


https://funvision.blogspot.com/2016/10/opencv-multiple-people-tracking-it-is.html/

Motion Tracking

http://camilleutterback.com/projects/text-rain/

Machine Vision in Industry



https://www.xyntekinc.com/default.aspx?pid=259

Object Detection

https://www.analyticsinsight.net/computer-vision-solving-real-world-problems-with-digital-visuals/

Veronese

The Wedding at Cana

Las Bodas de Caná

A Vision by

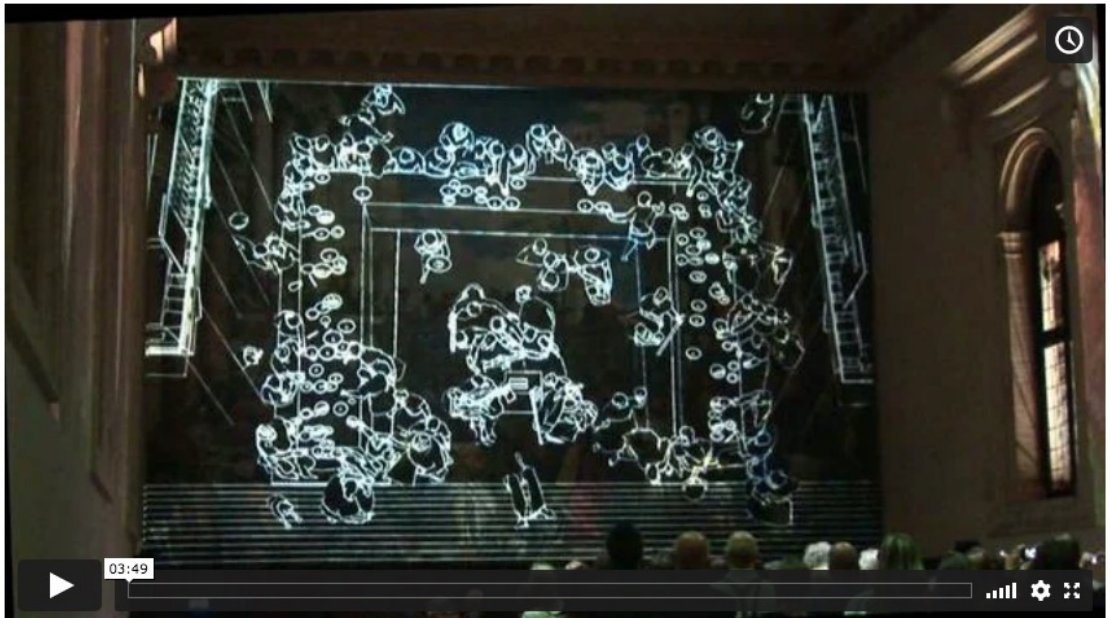
Una visión de

Peter Greenaway

PETER GREENAWAY ON VERONESE´S WEDDING AT CANA

SHARE

San Giorgio Maggiore, Venice



The second of Peter Greenaway's live projects onto a facsimile that was produced by Factum Arte. The performance took place in the original location of the great painting by Veronese: the refectory of San Giorgio Maggiore in Venice. Click here to know more about the process and production of the Wedding at Cana facsimile.

“Bitwalls”, Christian Moeller (2011)

https://segd.org/san-jose-international-airport-art-technology-program

“Netropolis | Berlin”, Michael Najjar (2003-2006)

https://www.michaelnajjar.com/artworks/netropolis#9

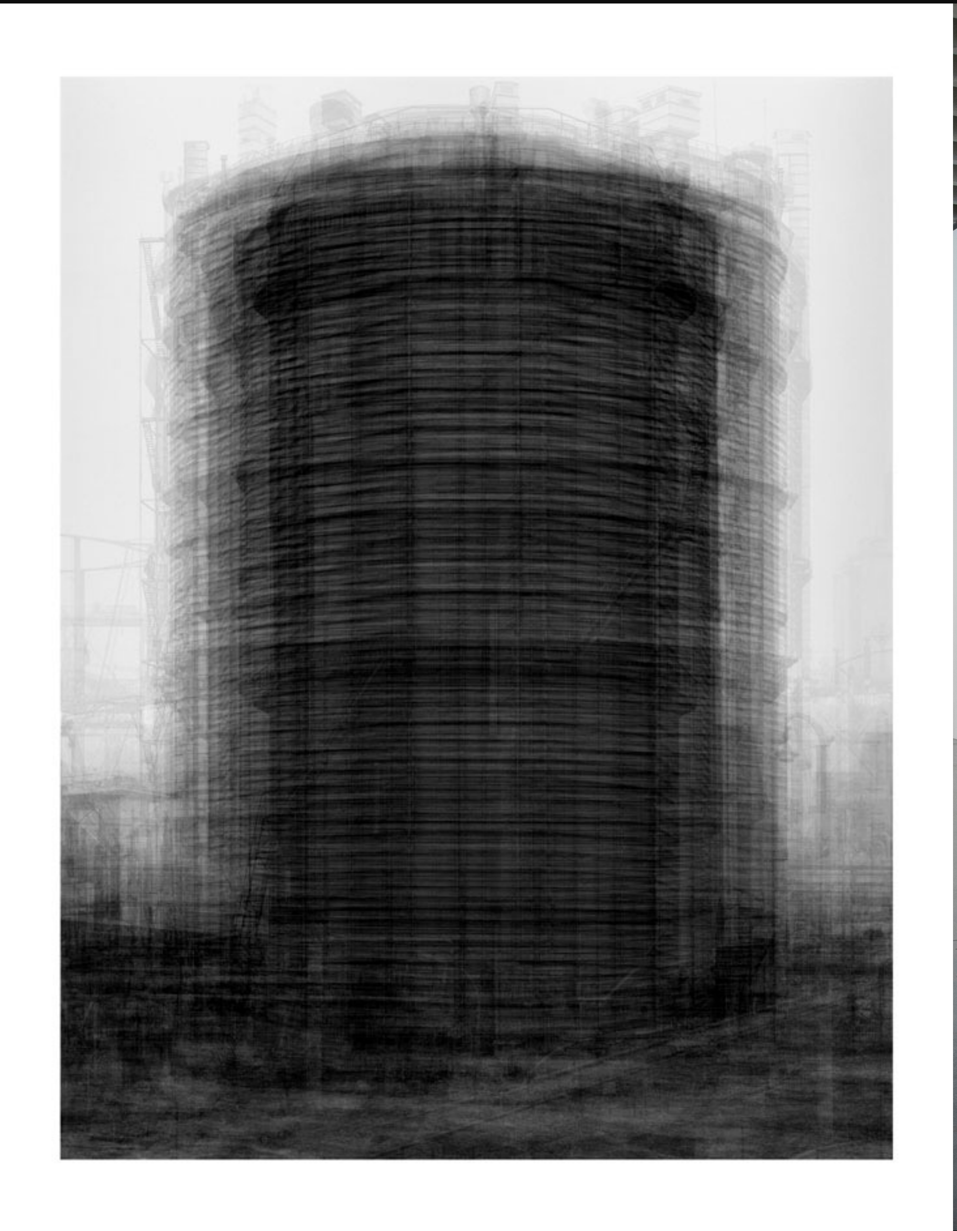
Multiple Image Layering

https://www.davidzwirner.com/artists/james-welling/survey

“Rembrandt”, “Velasquez”, Jason Salavon (2009/2010)

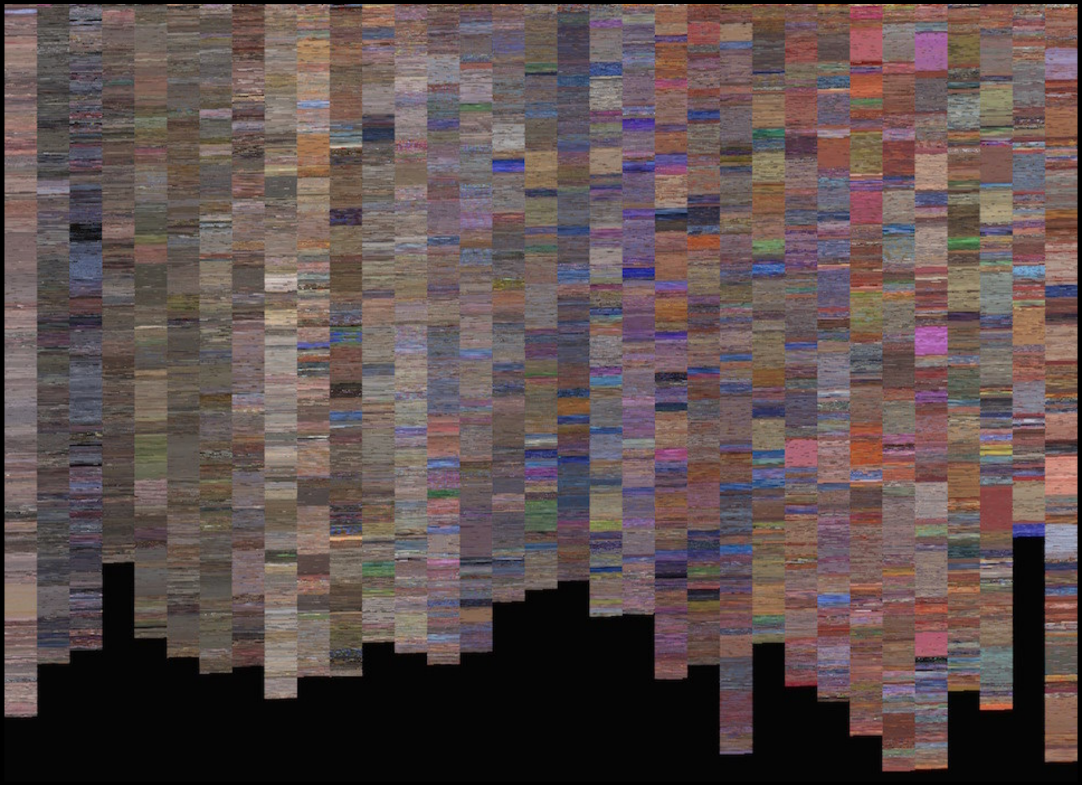
http://www.salavon.com/work/Portrait/

Idris Khan (2017)



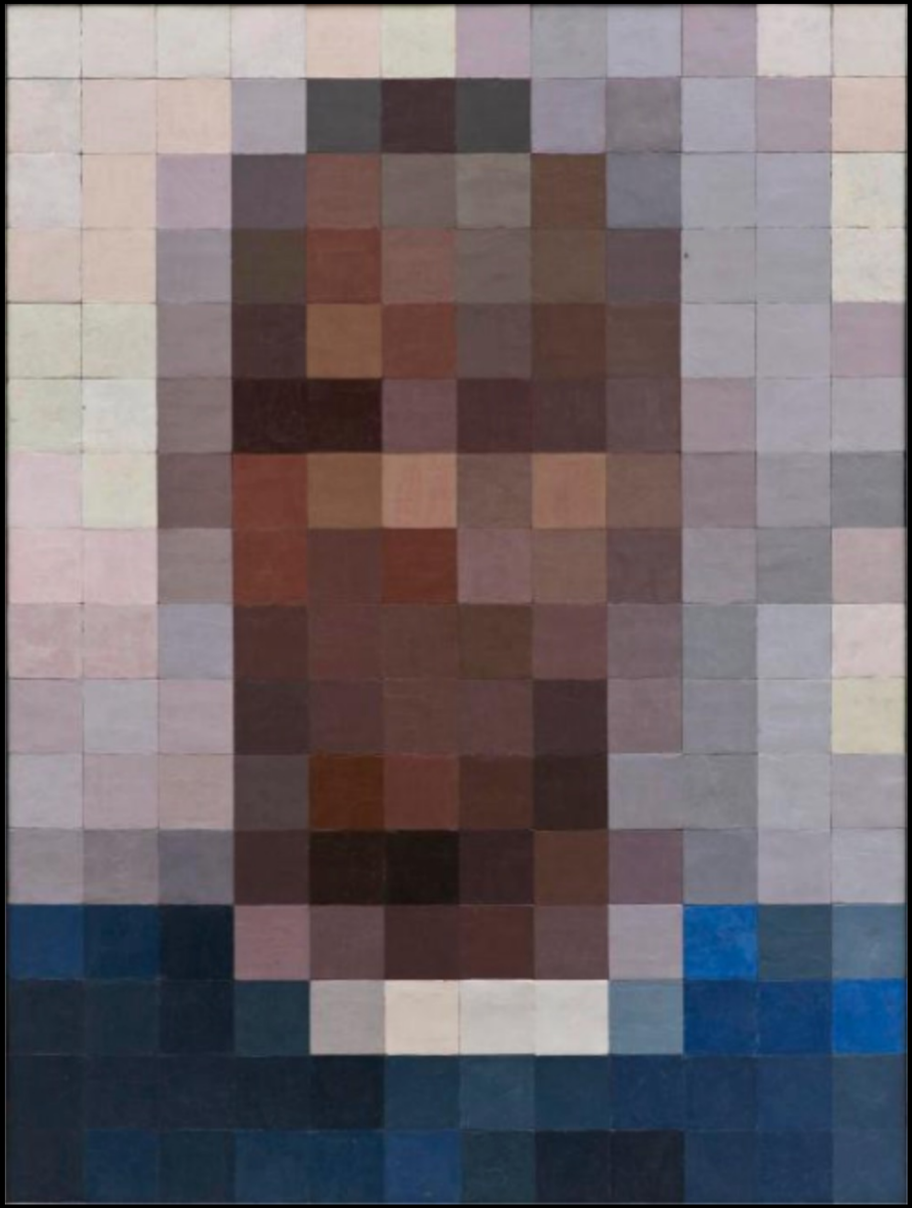
https://thenewartgallerywalsall.org.uk/exhibition/idris-khan/

A Palette of CCTV's Chinese New Year Gala, Fan Xiang(2017)

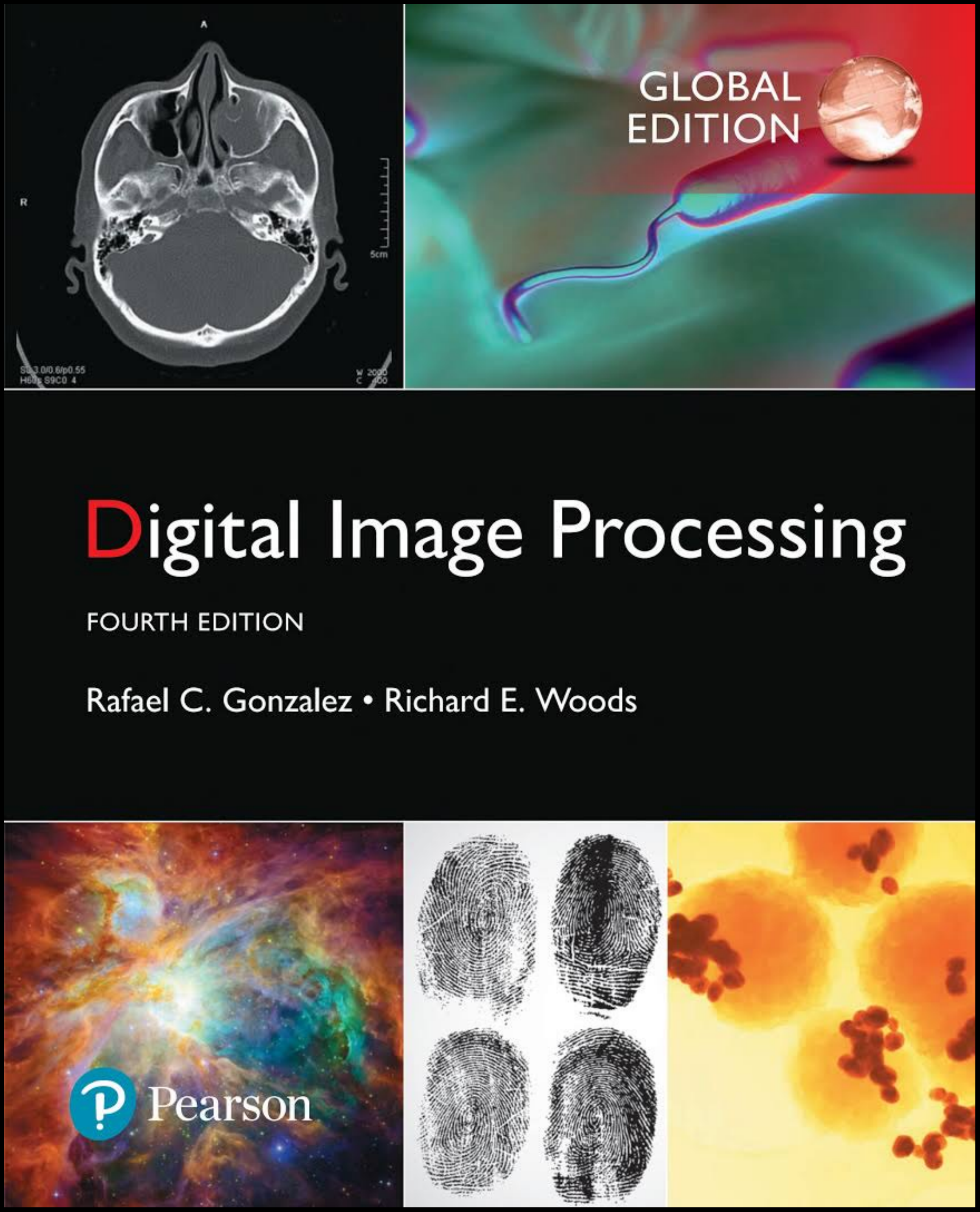


https://www.zeelab.xyz/A-Palette-of-CCTV-s-Chinese-New-Year-Gala-1

Channel 11, Kori Newkirk(1999)



https://collections.sbma.net/objects/29455/channel-11?ctx=ff44ff6419ab7cde85698f0d5c519c34b529cb20&idx=20



Gonzalez, Woods, R. E., & Woods, R. E. (Richard E. (1992). *Digital image processing / Rafael C. Gonzalez, Richard E. Woods.* Addison-Wesley.

To be continued…