Digitalization

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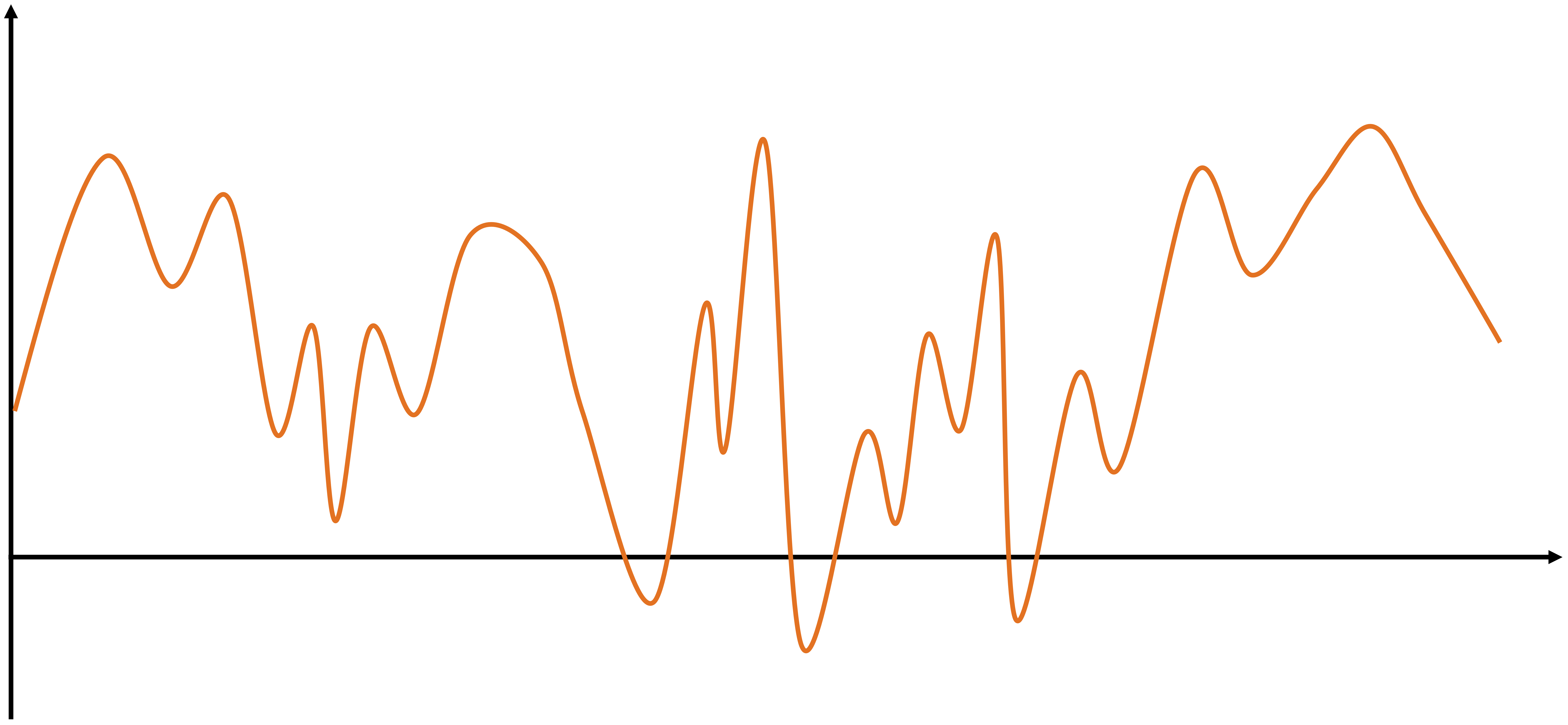
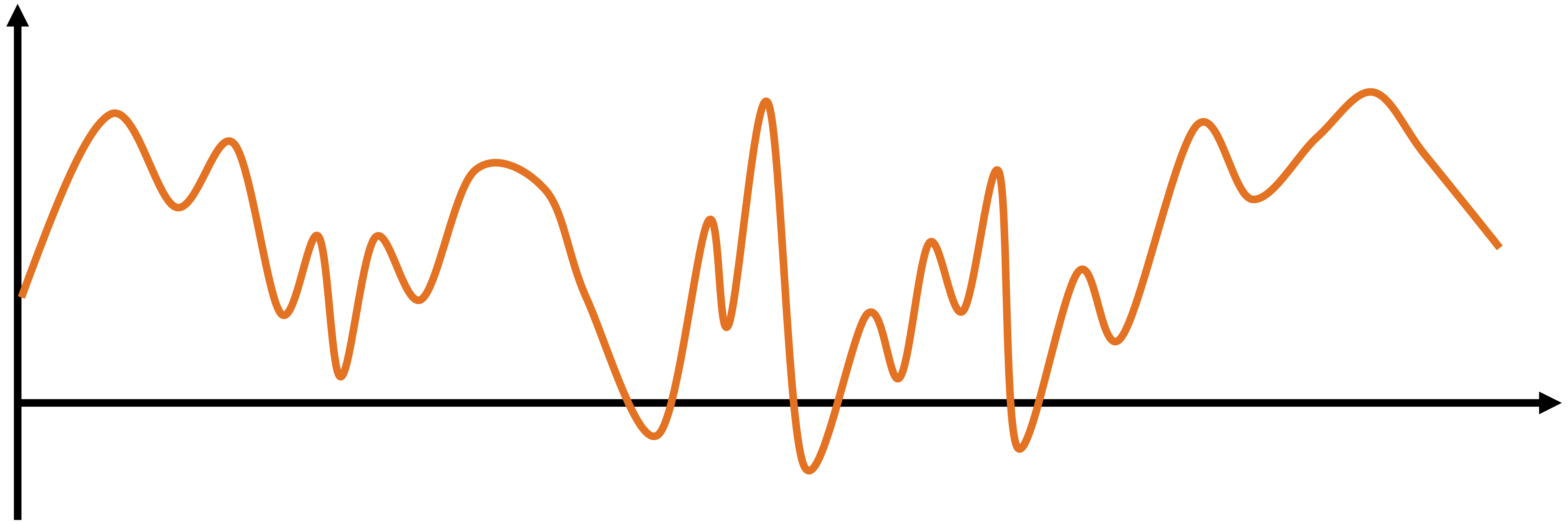
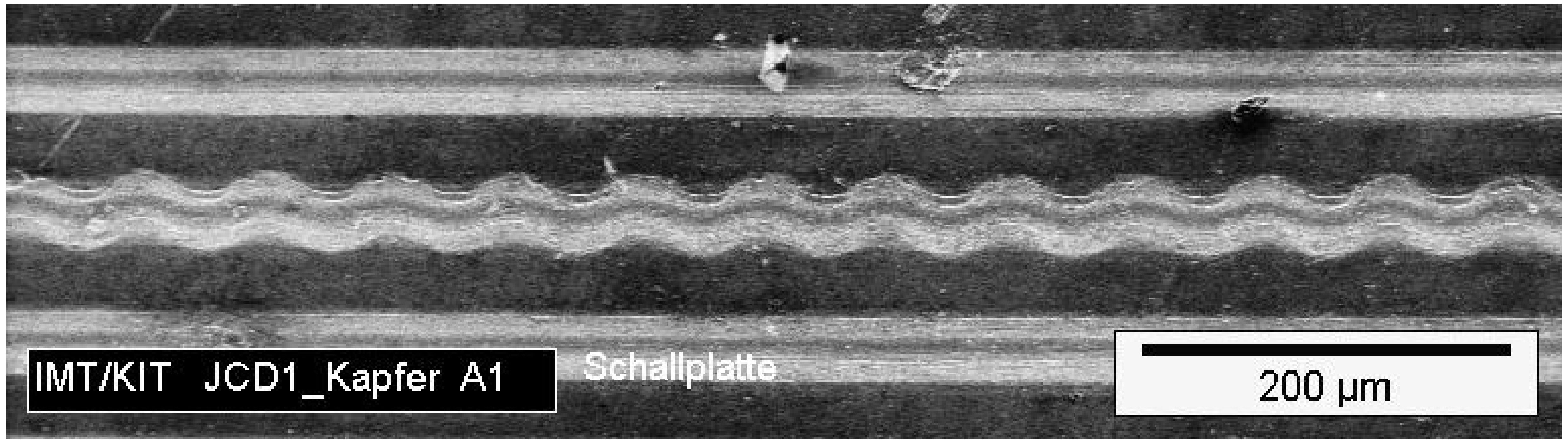
From Analog to Digital

An Analogous Signal



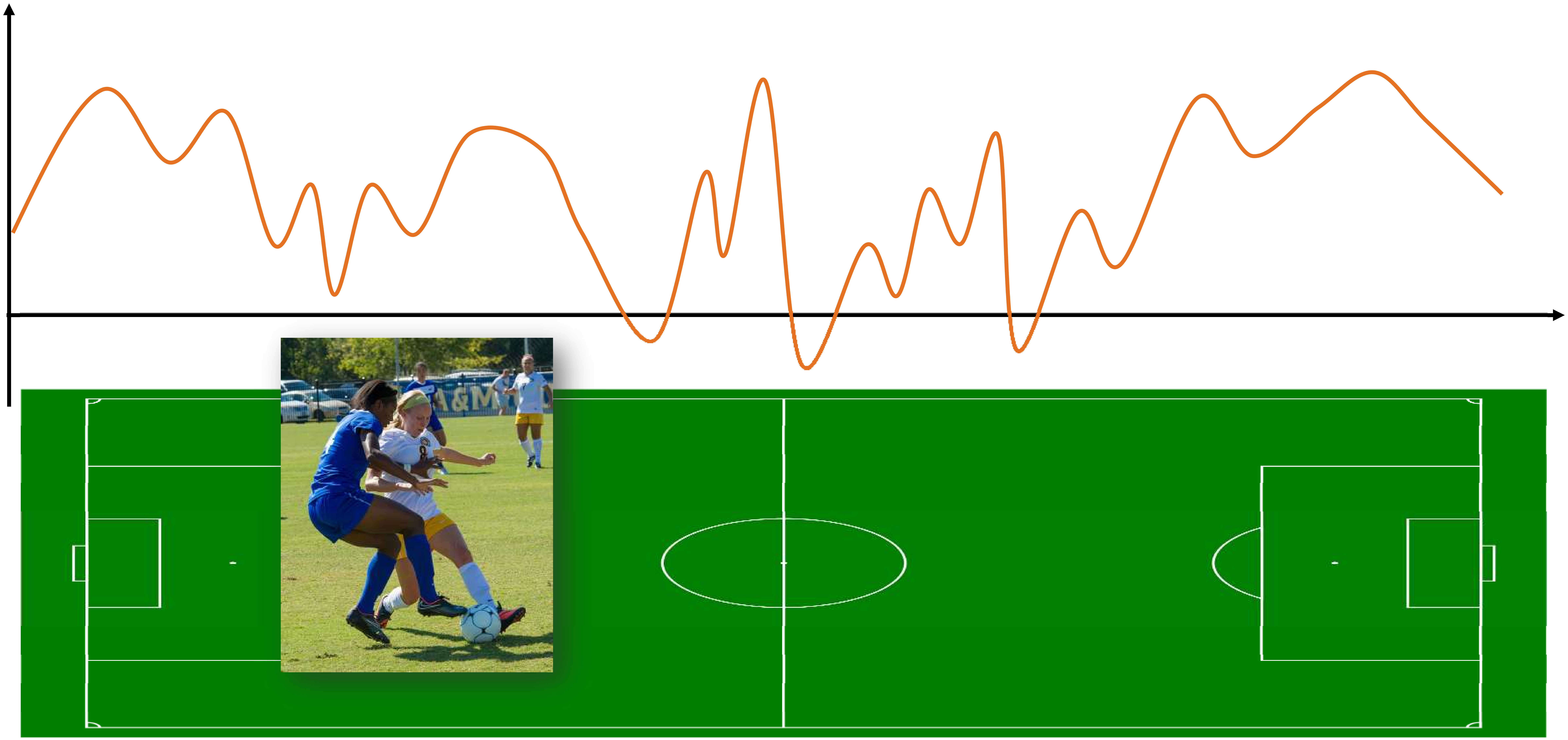
An Analogous Signal





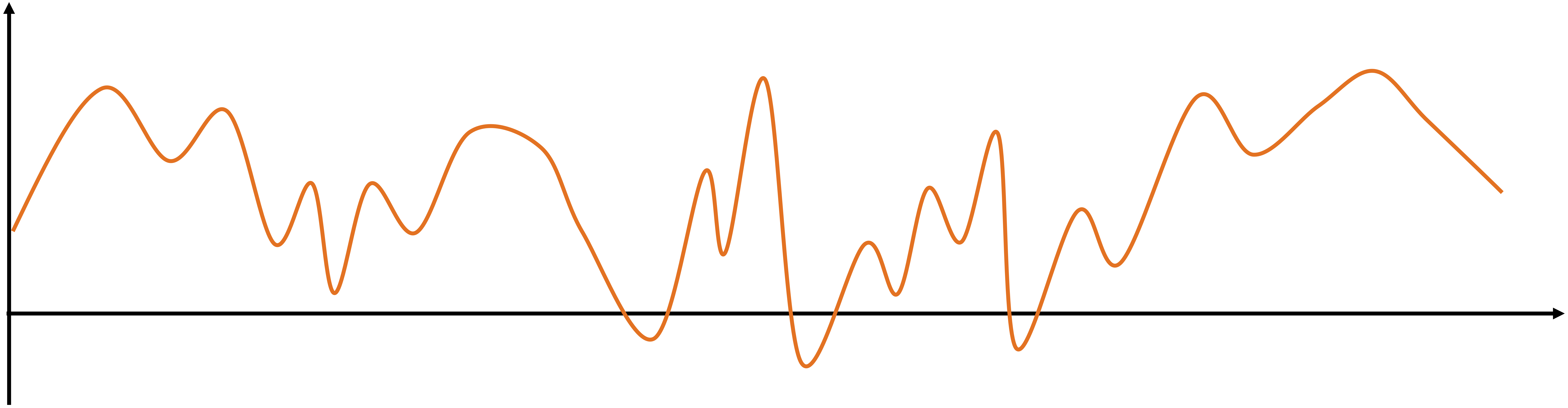
https://de.wikipedia.org/wiki/Schallplatte

An Analogous Signal



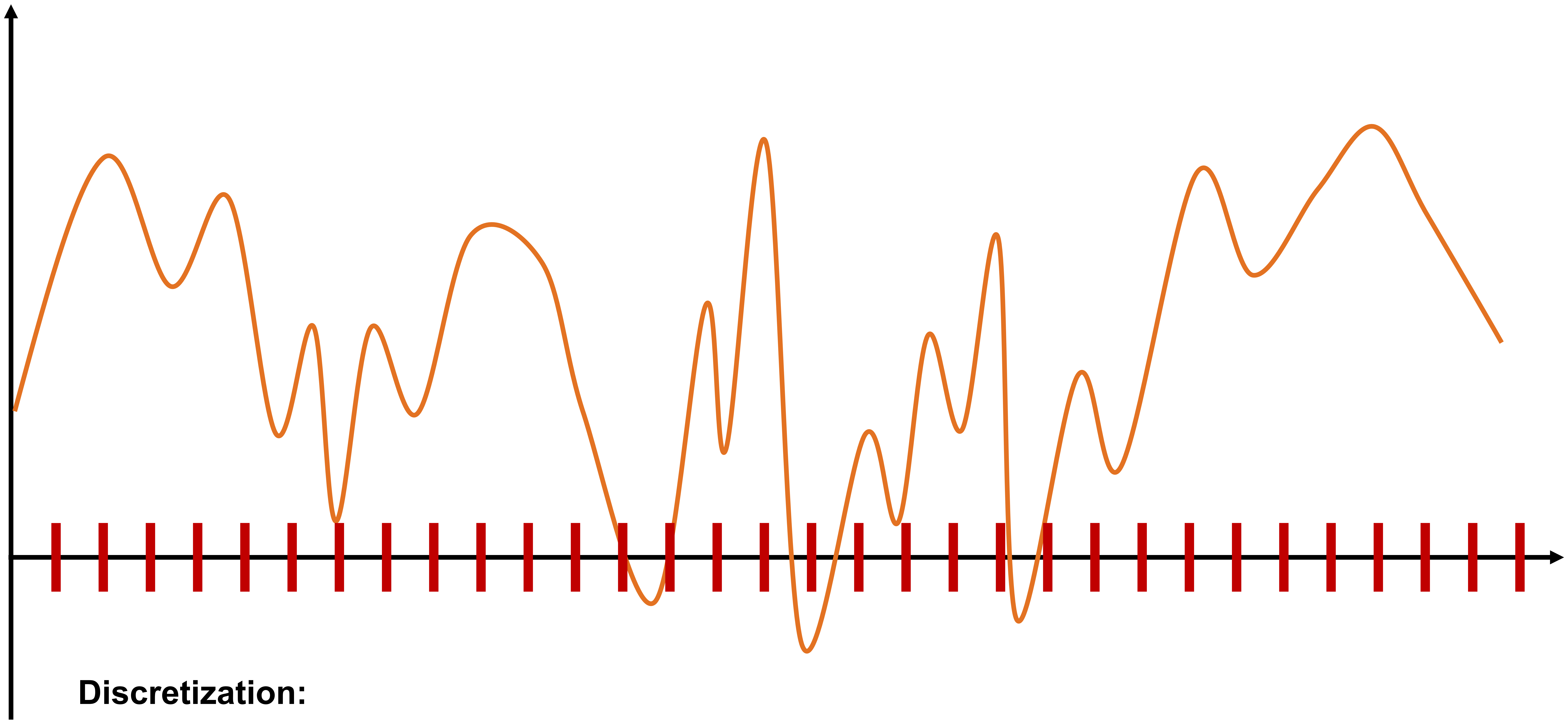
https://commons.wikimedia.org/wiki/File:Soccer_field_-_empty.svg
https://commons.wikimedia.org/wiki/File:Athletics-Soccer_vs_ASU-Senior_Day-6502_(15389909468).jpg

An Analogous Signal



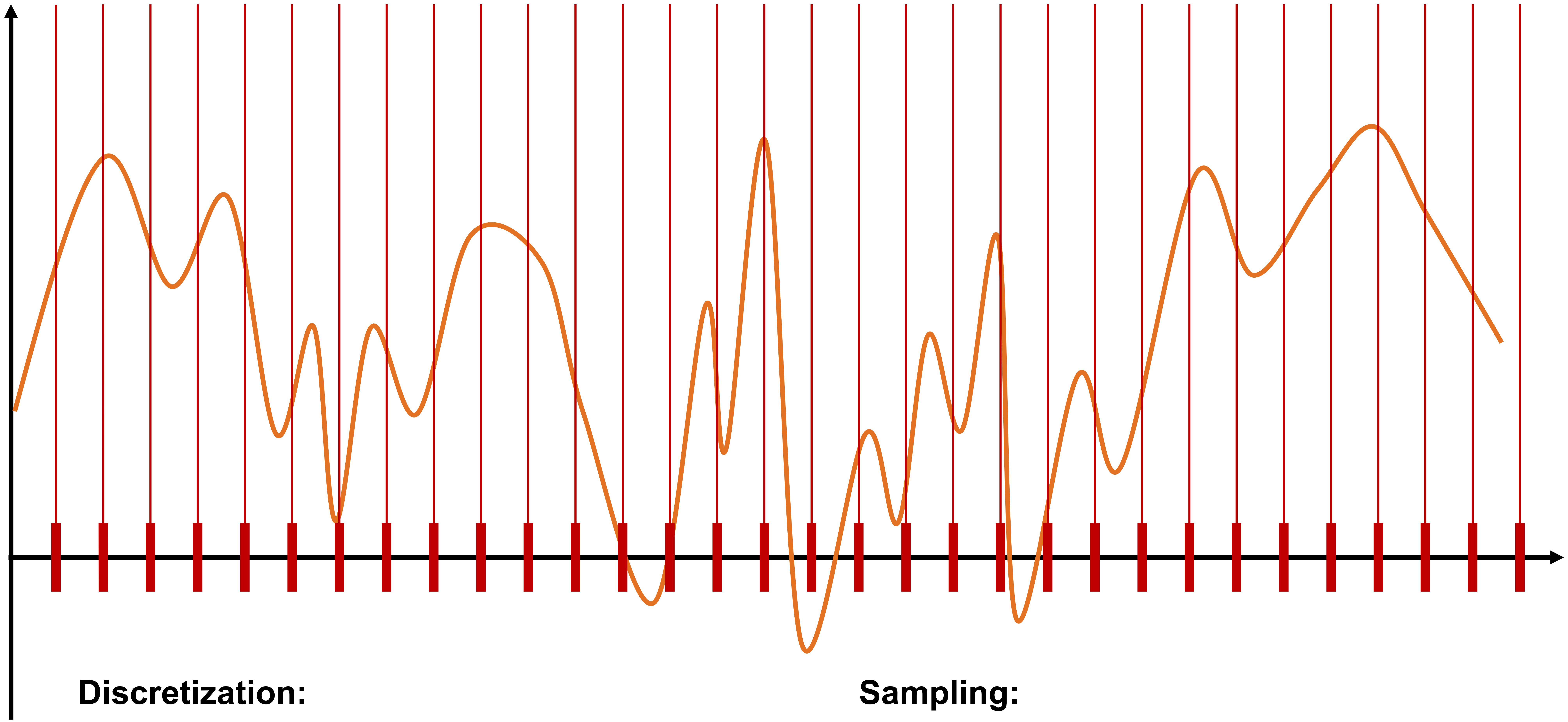
https://commons.wikimedia.org/wiki/File:2017-02-19-Panorama-Salzburg-Berge-1017-1021-60.jpg

Discretization



Discretization:
Fixing a grid of measuring points is defined on the axis over which the signal changes (time, space, …)

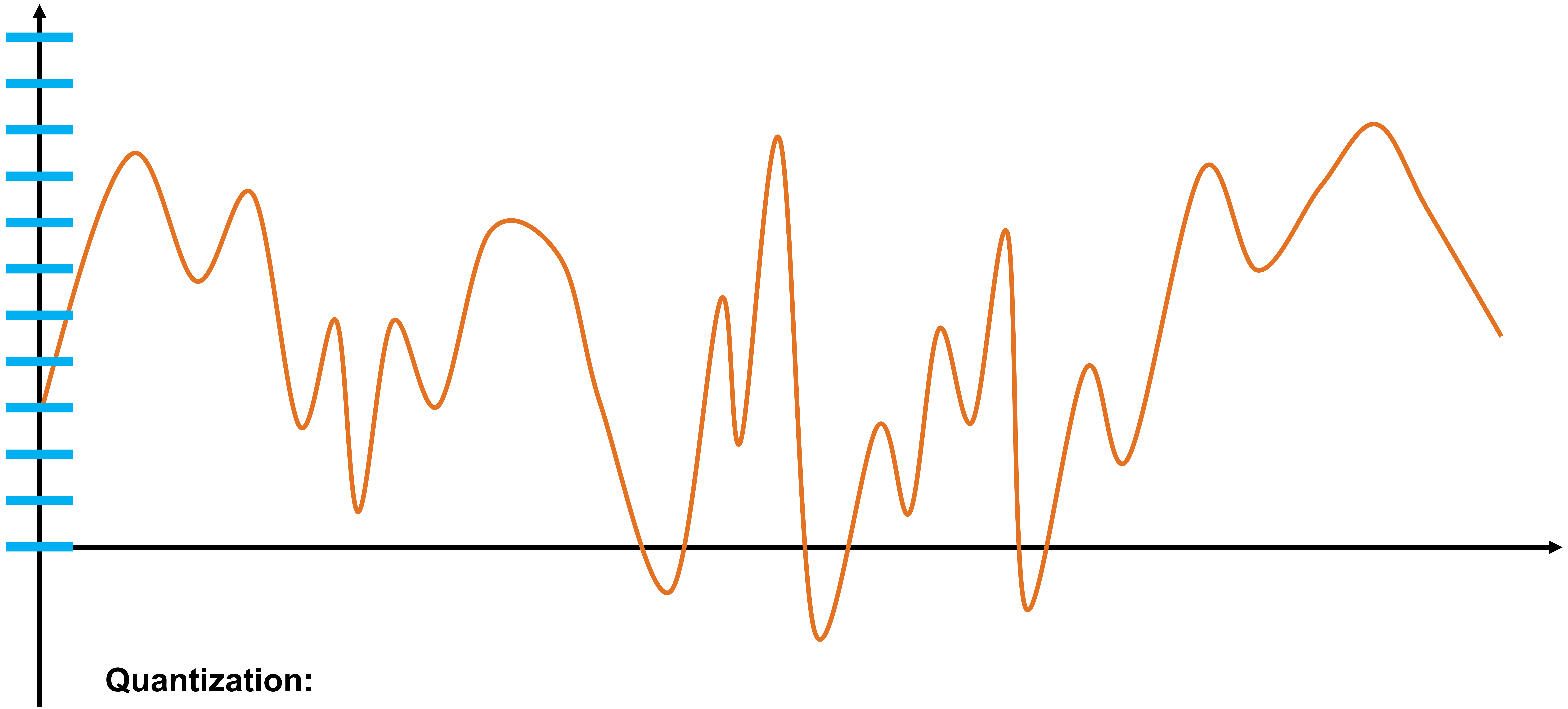
Discretization



Discretization:
Fixing a grid of measuring points is defined on the axis over which the signal changes (time, space, …)

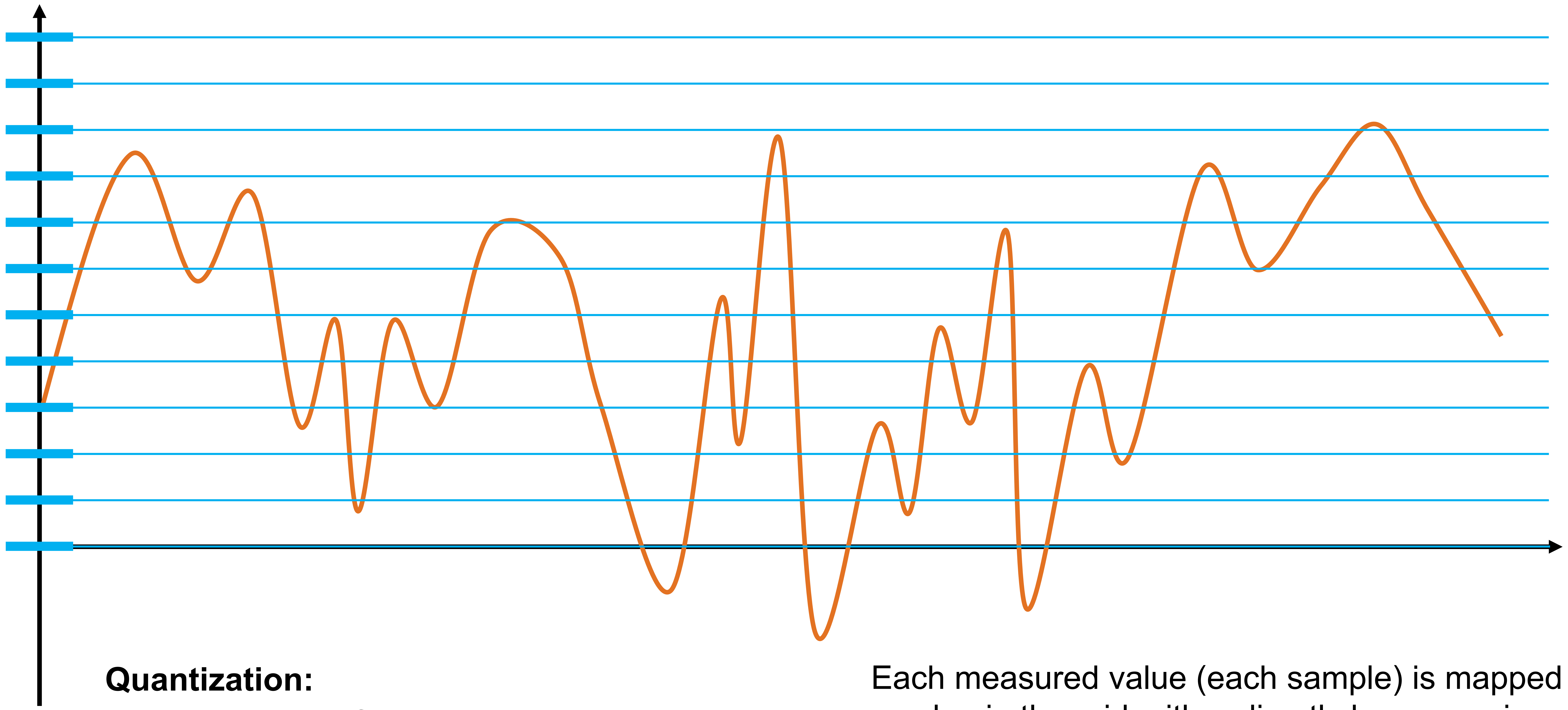
Sampling:
Determining the current value of the signal (*sample*) for each measuring point.

Quantization



Quantization:
Representation of the measured values in a fixed whole-numbered value grid

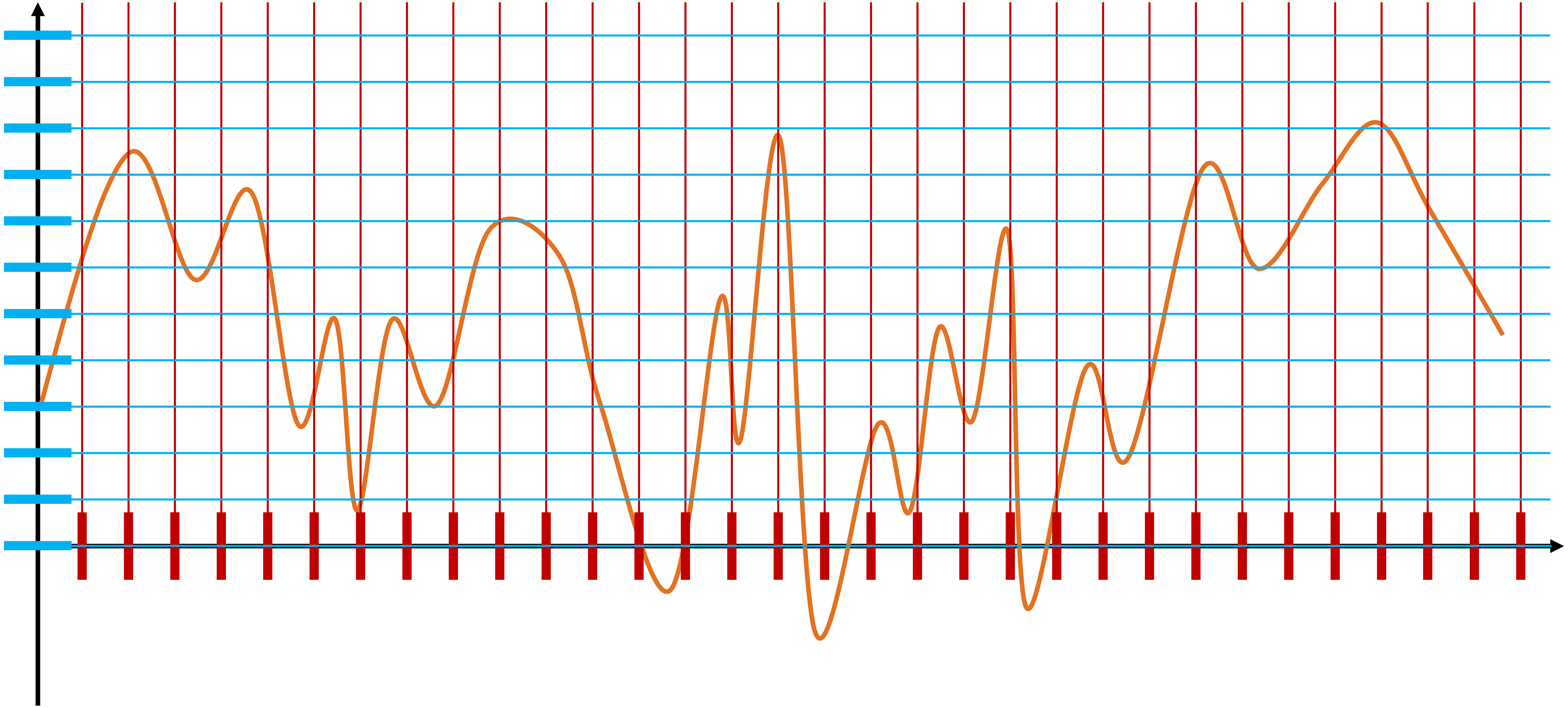
Quantization



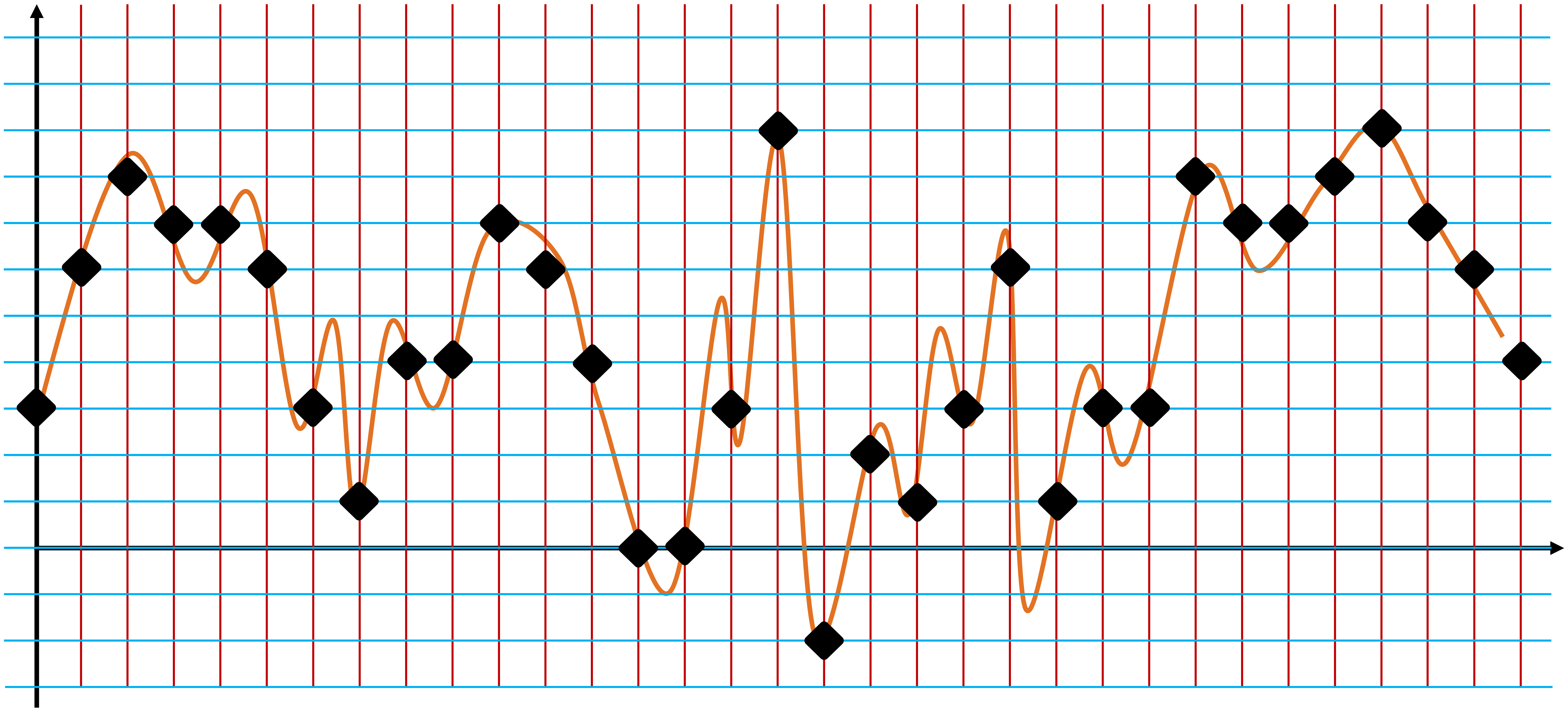
Quantization:
Representation of the measured values in a fixed whole-numbered value grid

Each measured value (each sample) is mapped to a value in the grid, either directly by measuring instruments or by calculation (e.g. rounding) from analog measurements.

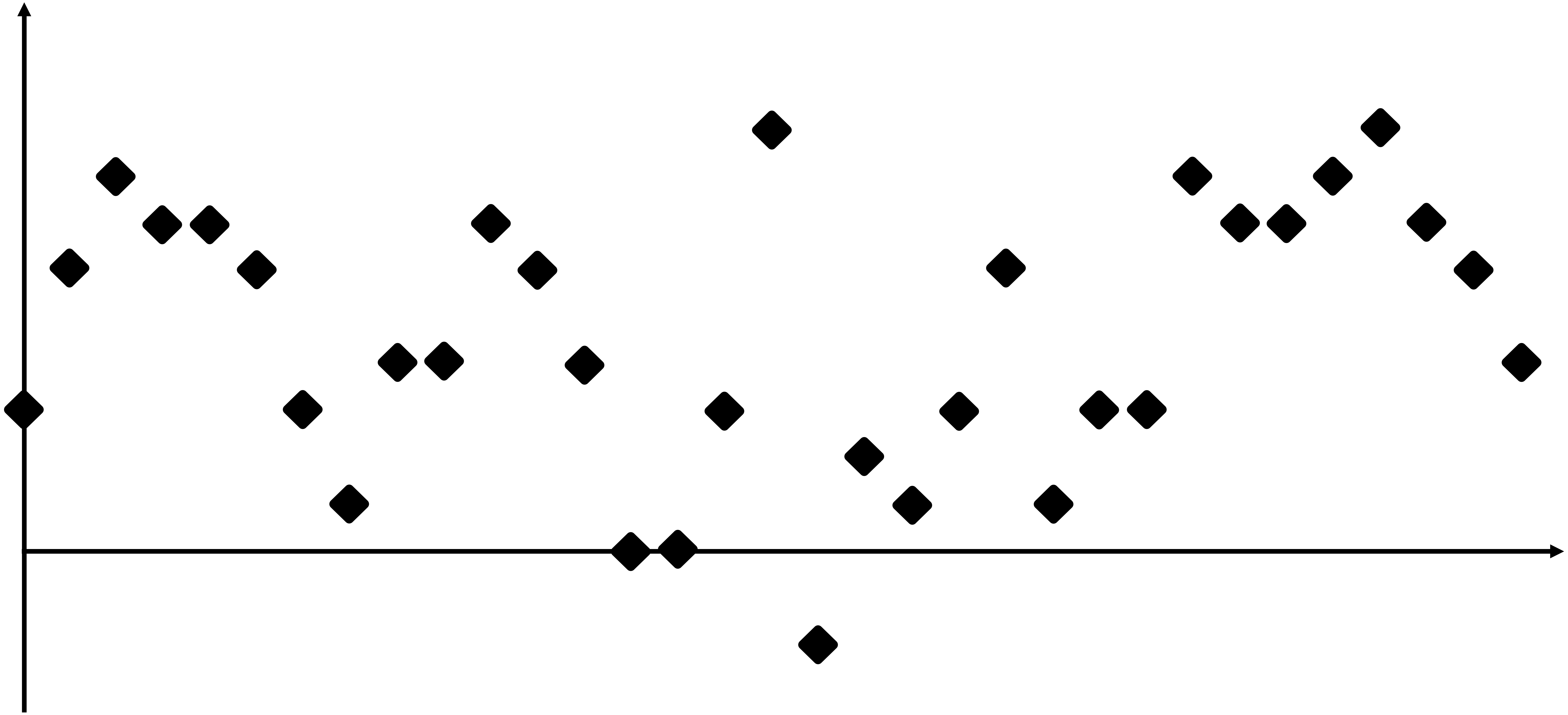
Discretization + Quantization = Digitization



Discretization + Quantization = Digitization



A Digital Signal



Bits and Bytes

Bits: smallest unit of storage, atomic, either 0 or 1

1 Bit is too small to be of much use

8 Bits together: 1 Byte

1 Byte can store:

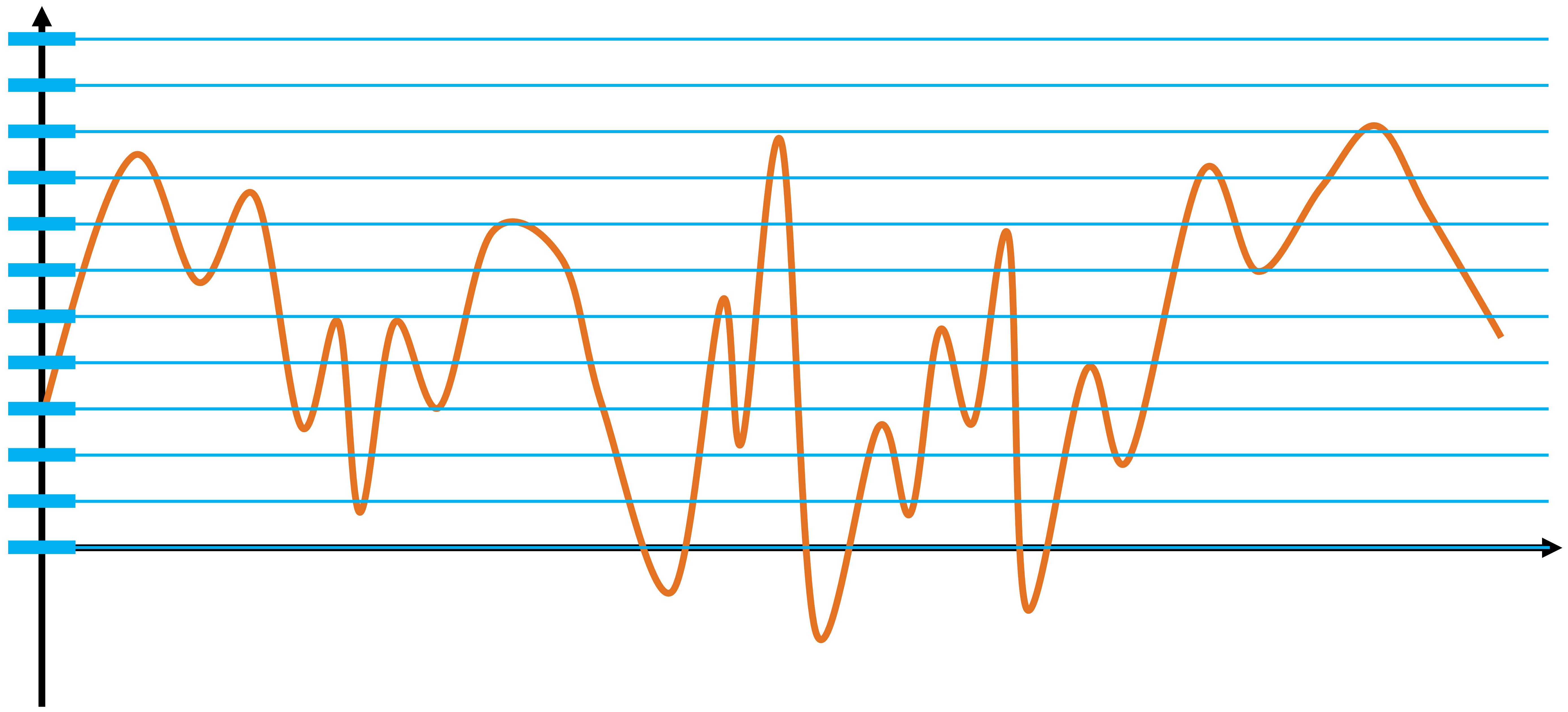
- 1 number between 0 and 255 or
- 1 character

Number of bits	Patterns
1	0 1
2	00 01 10 11
3	000 001 010 011 100 101 110 111

Bits and Bytes for Signals

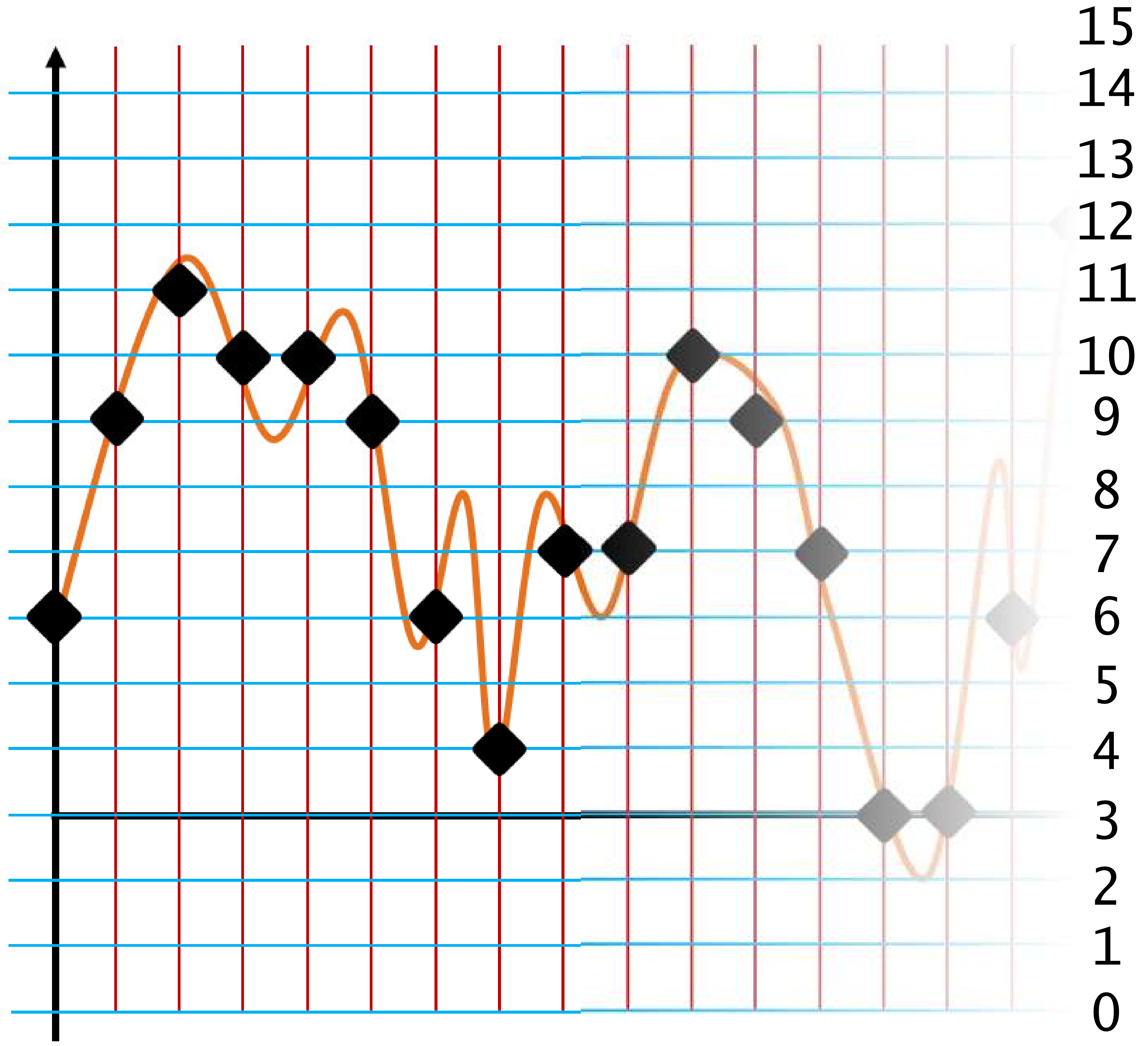
The number of steps in the quantization grid decides upon the required number of bits:

1 bit - 2 patterns
2 bits - 4
3 bits - 8
4 bits - 16
5 bits - 32
6 bits - 64
7 bits - 128
8 bits - 256 - one byte



n bits yield
2^n different patterns

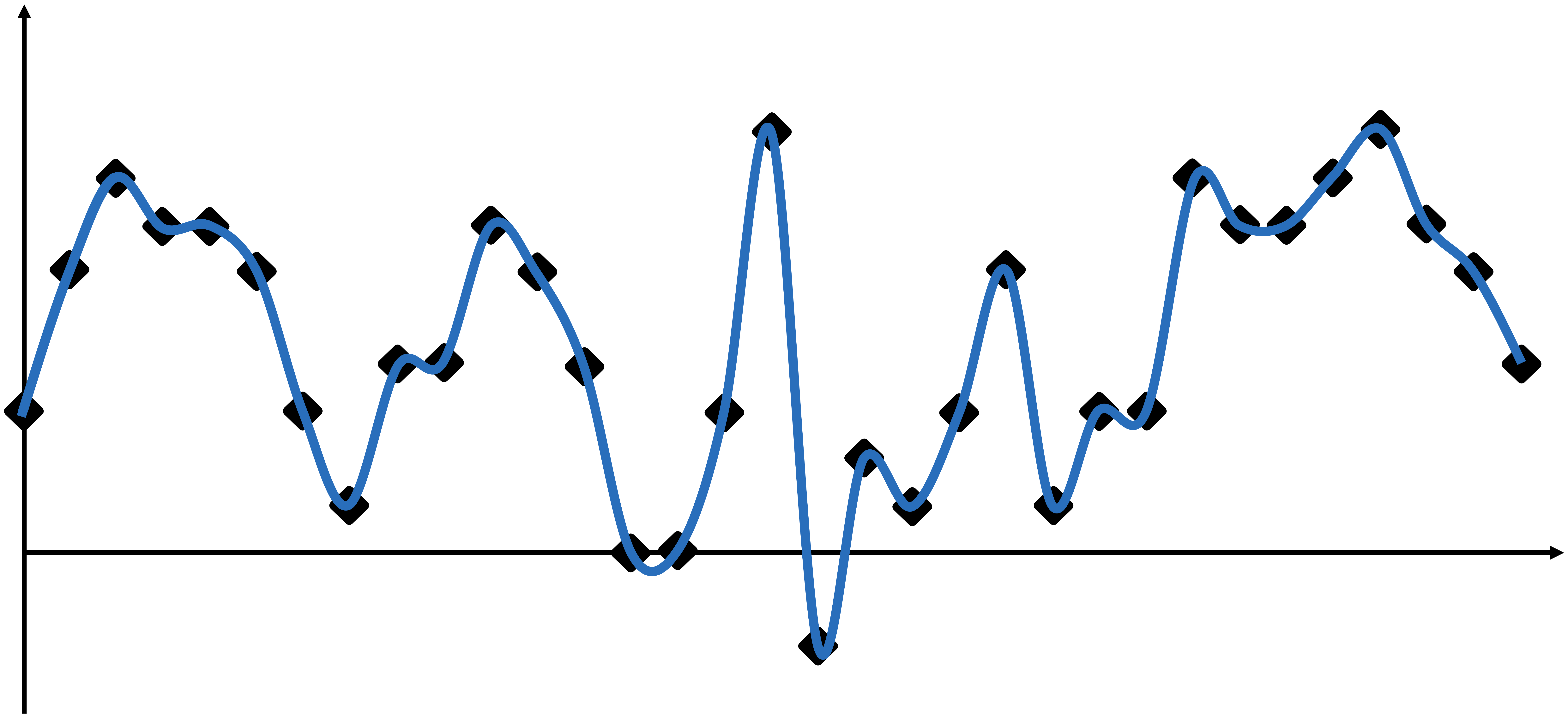
A Digital Signal



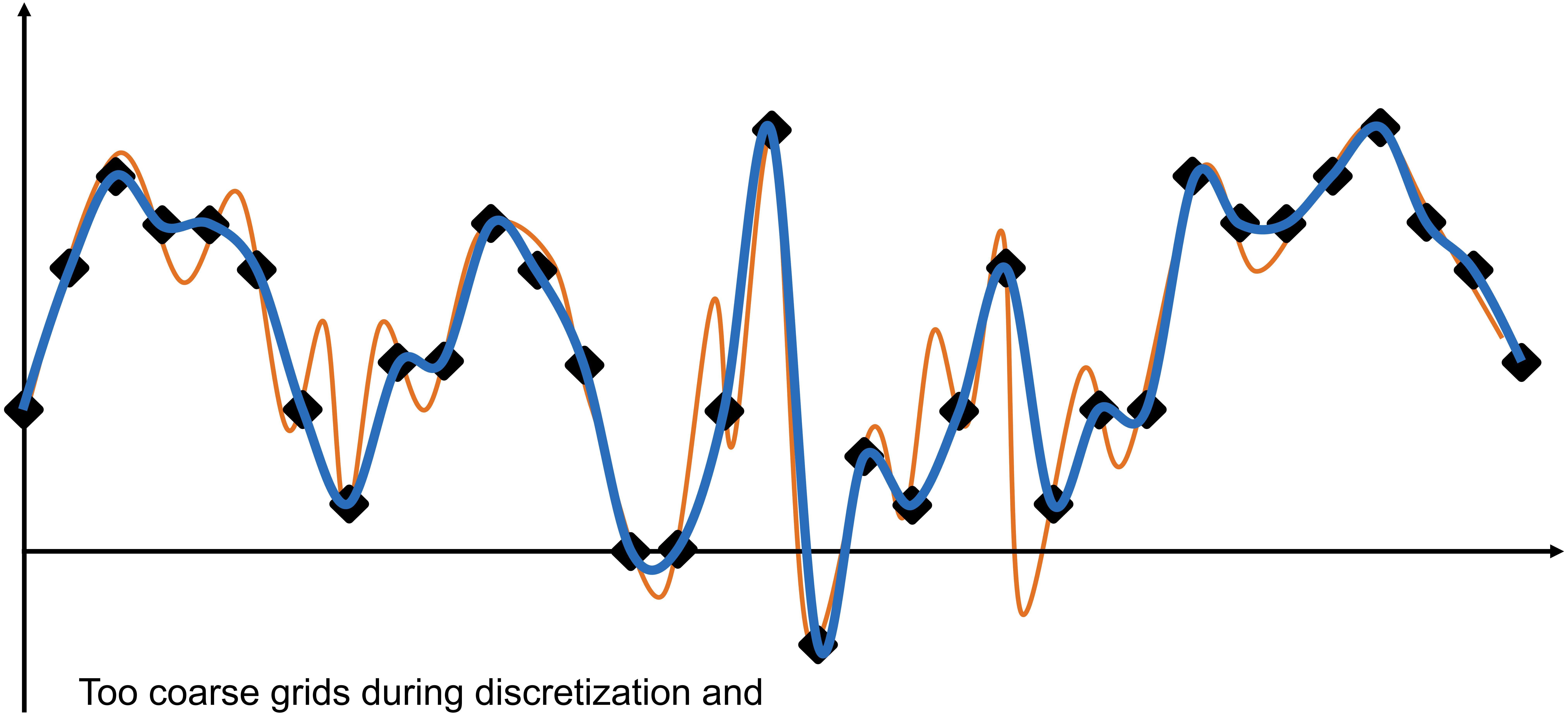
Time	Value	Pattern
1	6	0110
2	9	1001
3	11	1011
…		

The Signal:
0110 1001 1011 ...

Recovering an Analogous Signal



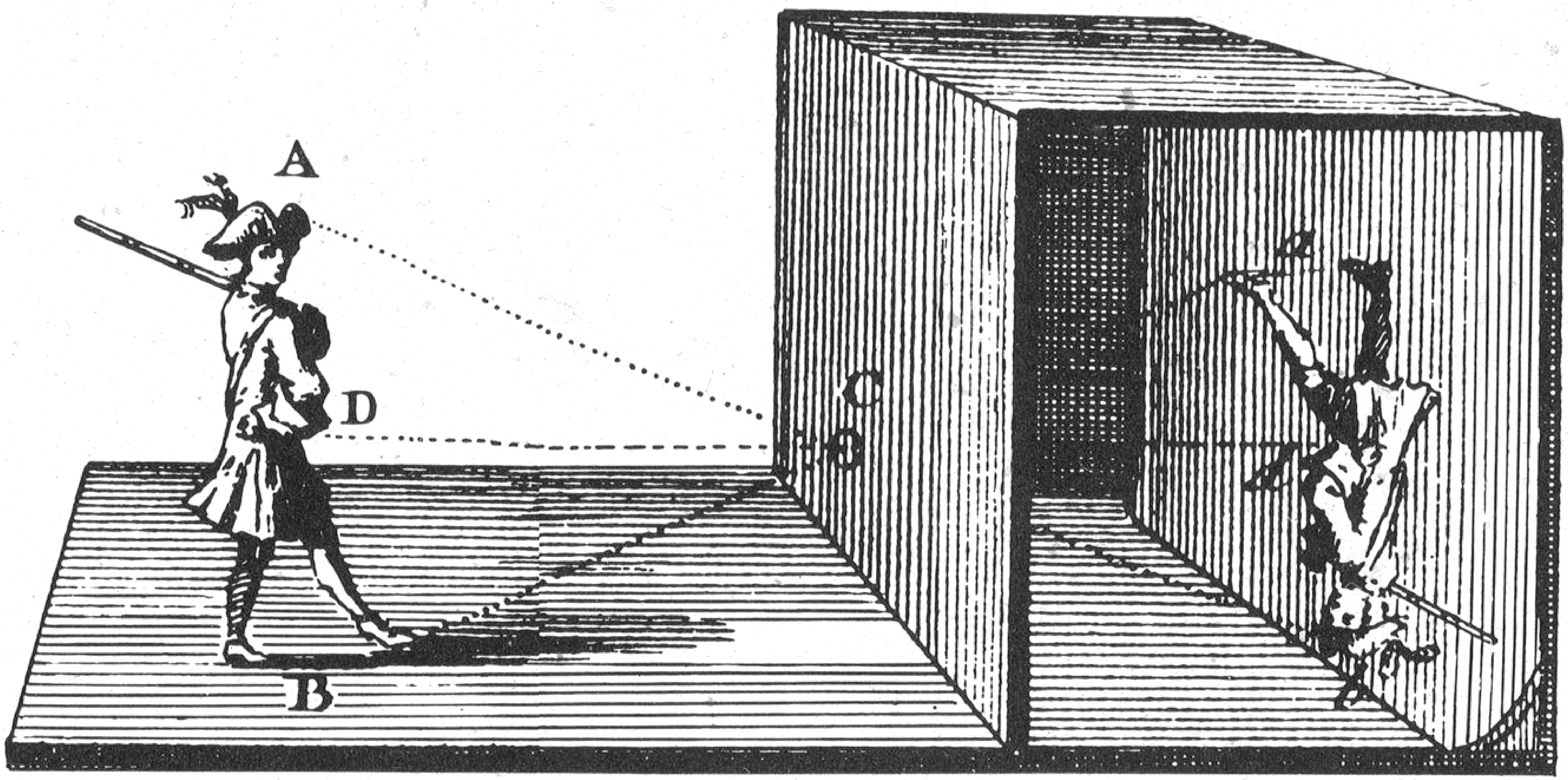
Digitizing Errors



Too coarse grids during discretization and quantization result in **digitization errors**.

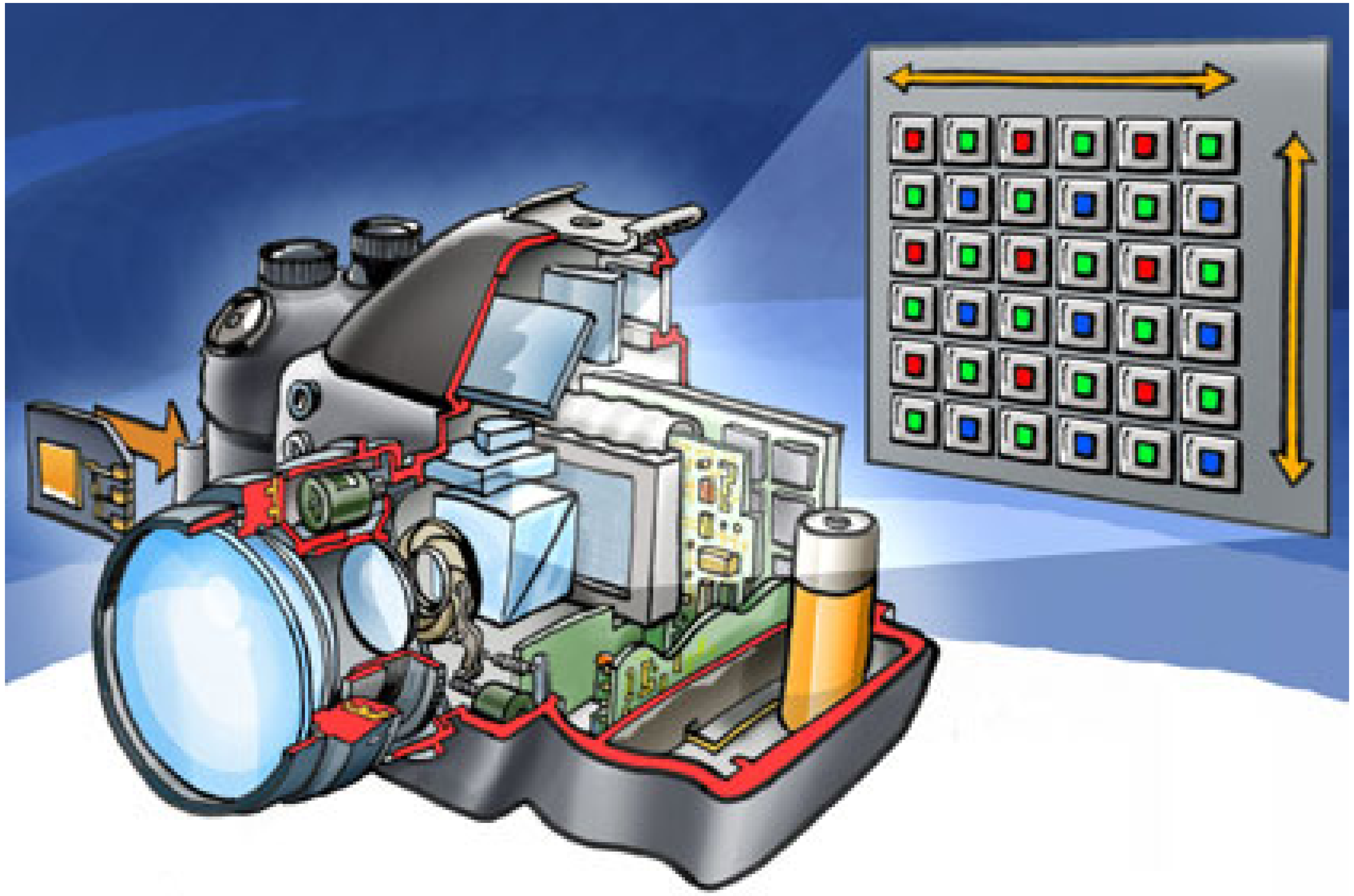
Digitizing Images

Camera Obscura



https://commons.wikimedia.org/wiki/File:001_a01_camera_obscura_abrazolas.jpg

Digital Camera



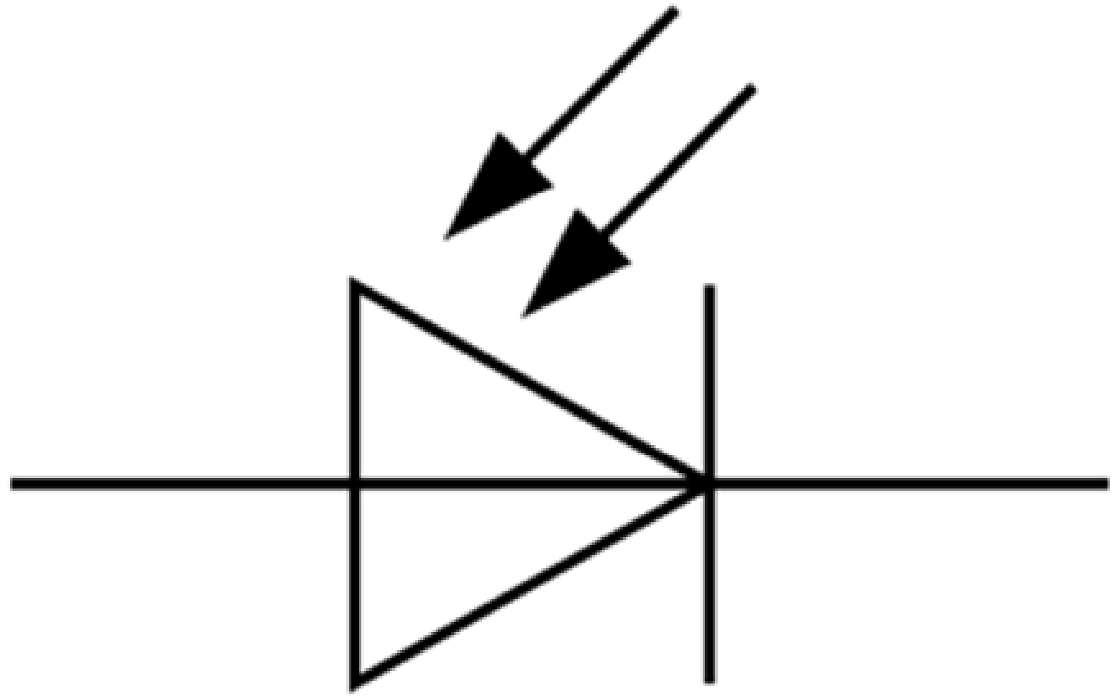
https://de.wikipedia.org/wiki/Datei:Chipincamera.jpg

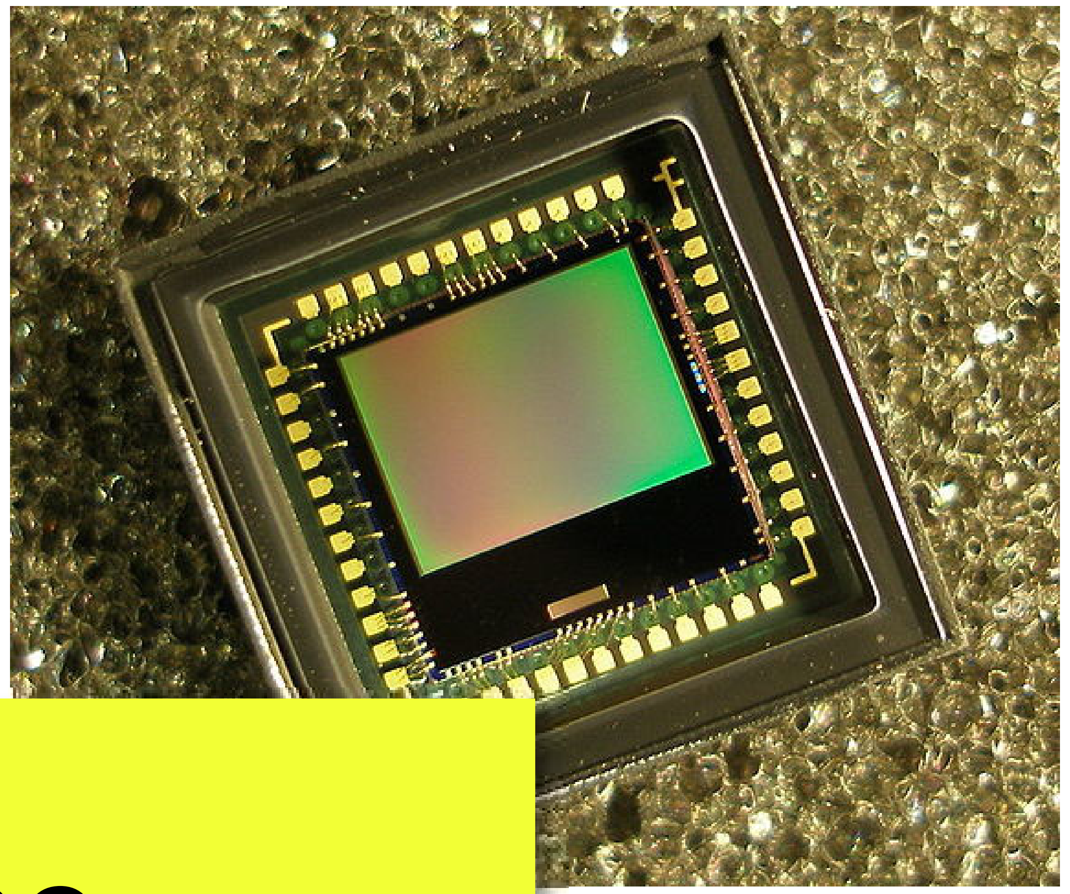
Analog-to-Digital Conversion of Light

Basically, a photodiode on a sensor translates luminance to a voltage and thereby reports the luminance of *one pixel*.

On approx. 12-35mm², current CMOS sensors have 12-108MP, i.e. 12-108 *Million Pixels*

A Photodiode takes up around 0,7µm in a current camera phone





CMOS Sensor

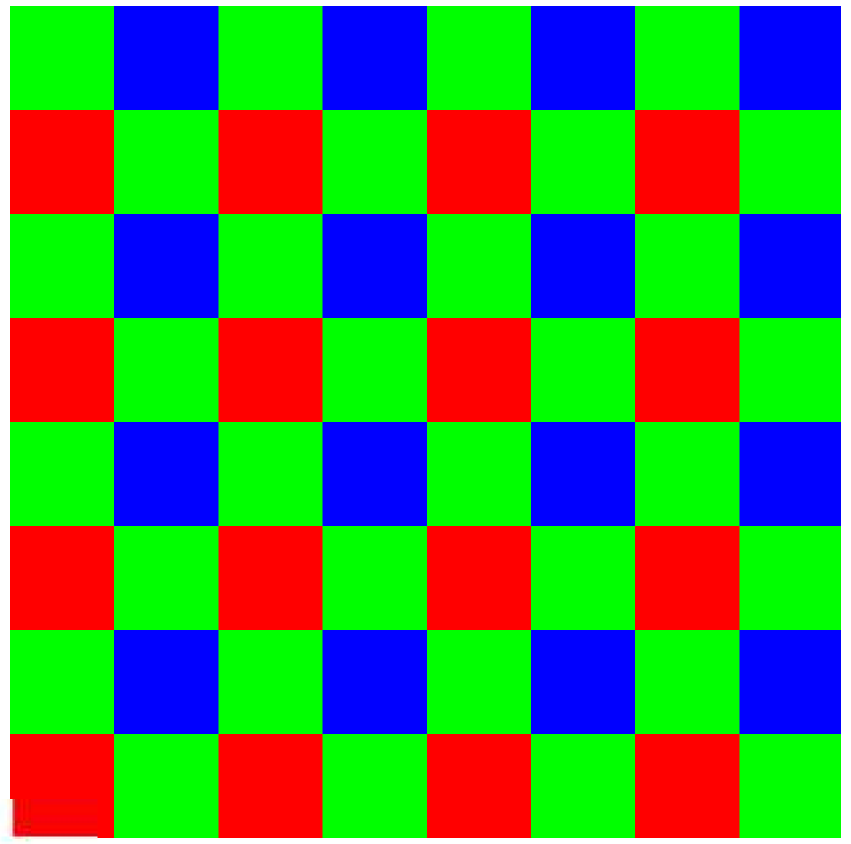
Where does the color come from?

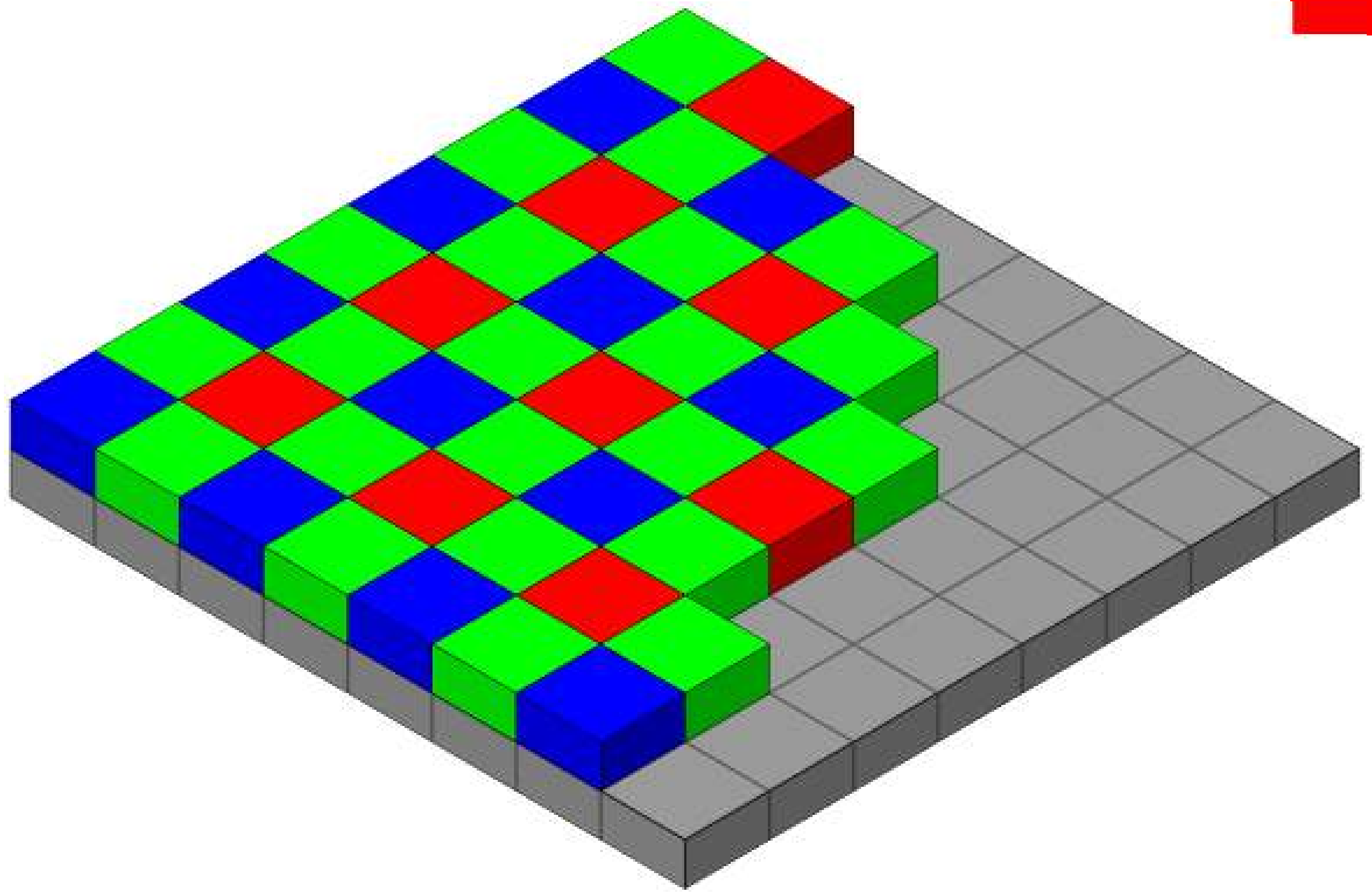
https://en.wikipedia.org/wiki/File:Matrixw.jpg

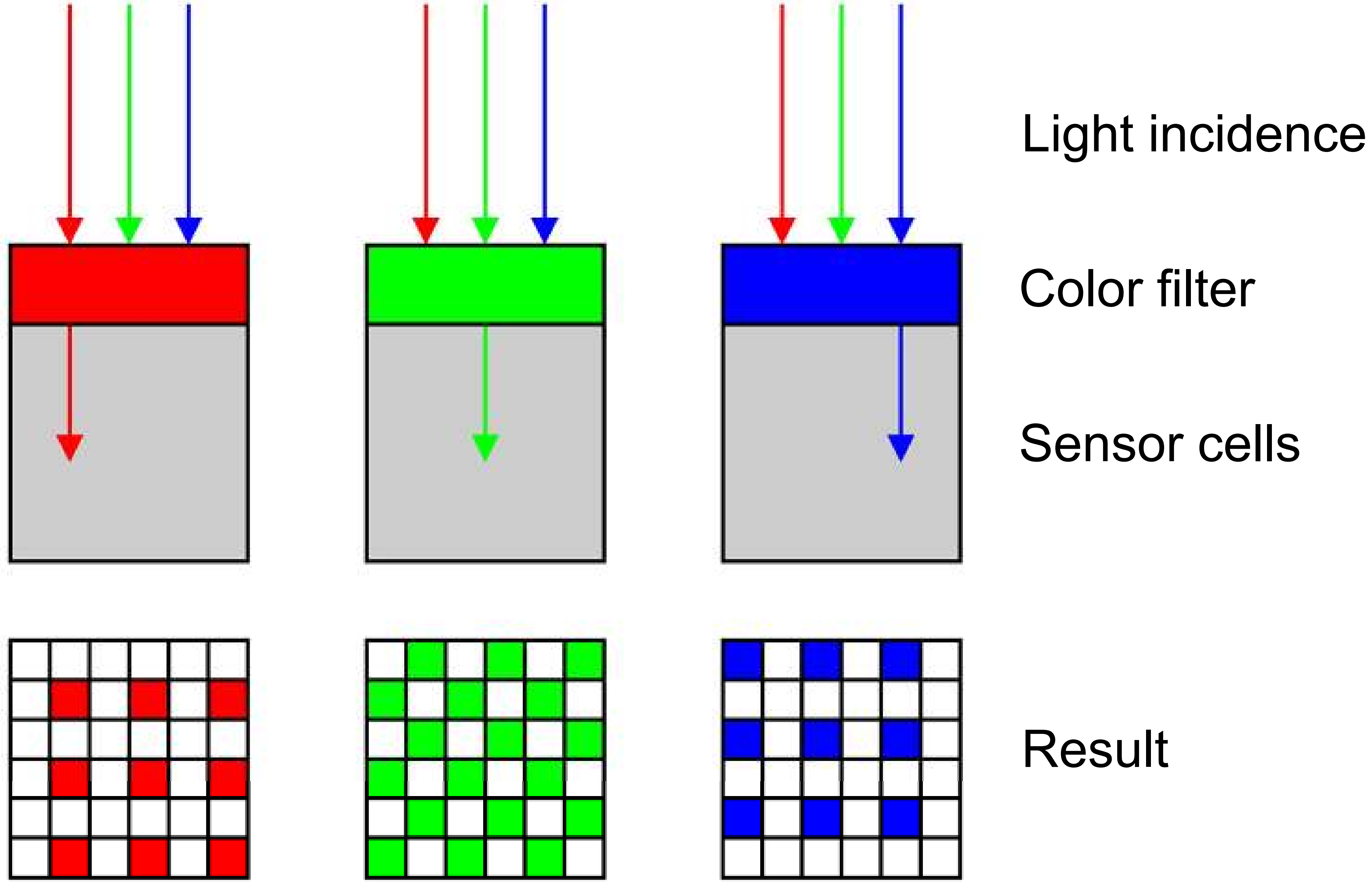
Bayer Sensors and Filters

Arrangements of RGB color filters on sensor arrays containing

- 50% green
- 25% red
- 25% blue filtered cells







Explanation:

Green component in gray tones makes the greatest contribution to the human eye's perception of brightness and thus also to the perception of contrast and sharpness.

72% of the brightness and contrast perception of gray tones is caused by their green component, whereas red contributes only 21% and blue only 7%.

https://en.wikipedia.org/wiki/Bayer_filter

Sensor Architectures

Earlier: CCD (*Charged Coupled Device*) sensors,
Mostly replaced by CMOS (*complementary MOS* or *Active-Pixel-*) sensors.

Both chip designs have their dis-/advantages

Disadvantage of CCD: Blooming

Disadvantage of CMOS: Rolling Shutter

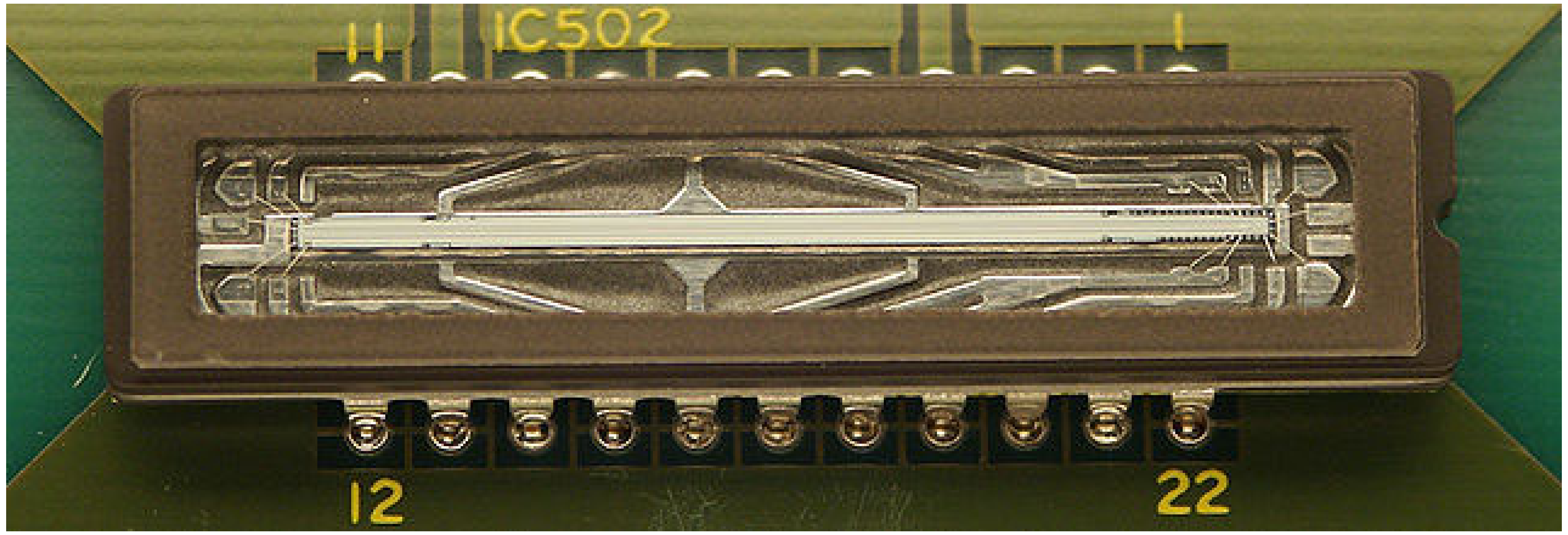
https://en.wikipedia.org/wiki/File:Blooming_ccd.jpg
https://en.wikipedia.org/wiki/File:Helicopter_taking_off_at_Hat_Yai_Hospital,_November_2010.jpg

Scanners

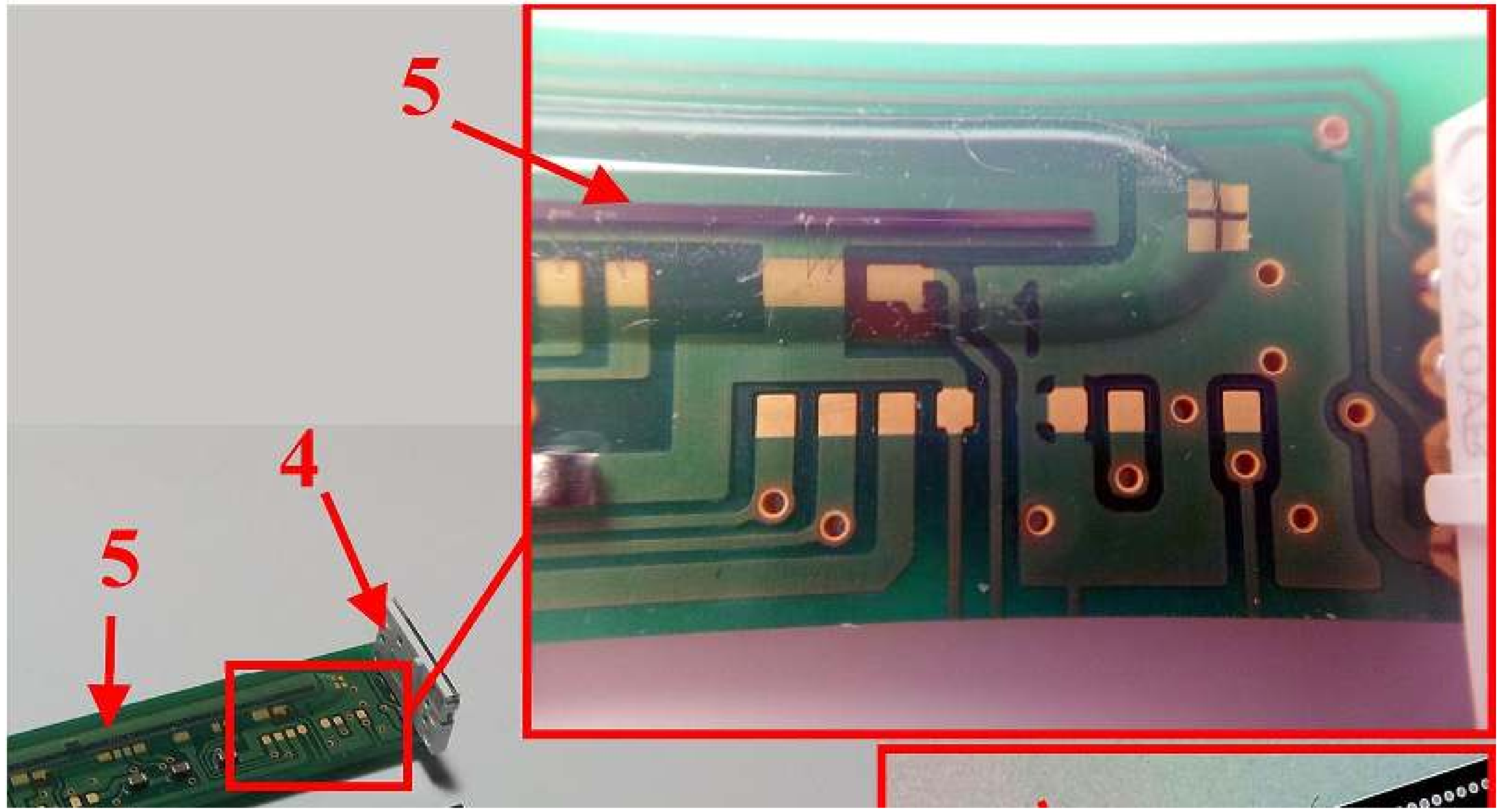
Flat bed scanners have a sensor with photodiodes arranged in lines.

Current flat bed scanners tend to have a CMOS-based CIS (*contact image sensor*):

- Cheaper
- Complex optical lense obsolete (for CCD-based scanners)
- Less power consumption – can be operated on USB power



CCD line sensor



CIS sensor and LEDs

https://de.wikipedia.org/wiki/Datei:Overwiew_-_Scanner_unit_CIS_Canon_MP500_5of5.jpg
https://commons.wikimedia.org/wiki/File:CCD_line_sensor.JPG

Book Scanners

https://www.youtube.com/watch?v=03ccxwNssmo

https://www.youtube.com/watch?v=cmhIJOqepVU

https://www.treventus.com
https://www.bsb-muenchen.de/article/20-jahre-innovative-digitale-bibliotheksdienstleistungen-bayerische-staatsbibliothek-feiert-jubilaeum-ihres-muenchener-digitalisierungszentrums-1916/

Digital Images

Representing Digital Images with Three Dimensions

Images have two spatial dimensions (x,y)

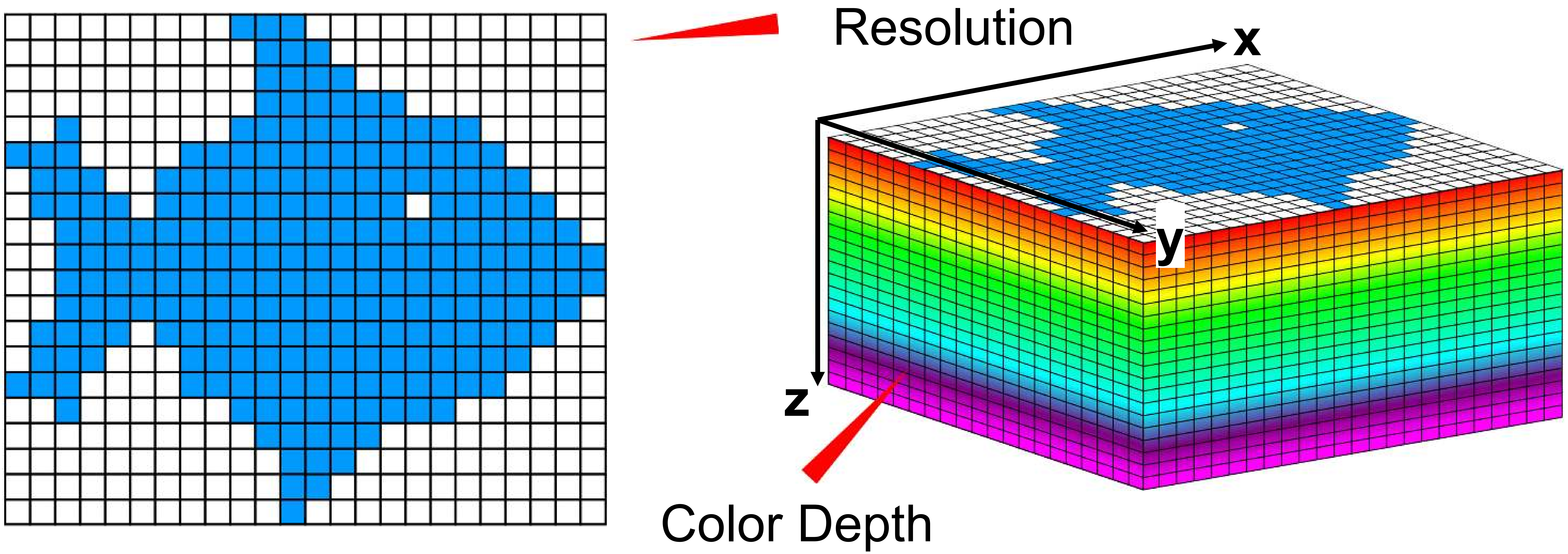
Third dimension (z-axis) specifies color(s)

https://commons.wikimedia.org/wiki/File:Albufeira_beach_portugal.jpg

Precision of Discretization & Quantization

Precision of discretization: spatial resolution, e.g. amount of “dots per inch” (dpi)

Precision of quantization: color depth, i.e. number of available colors

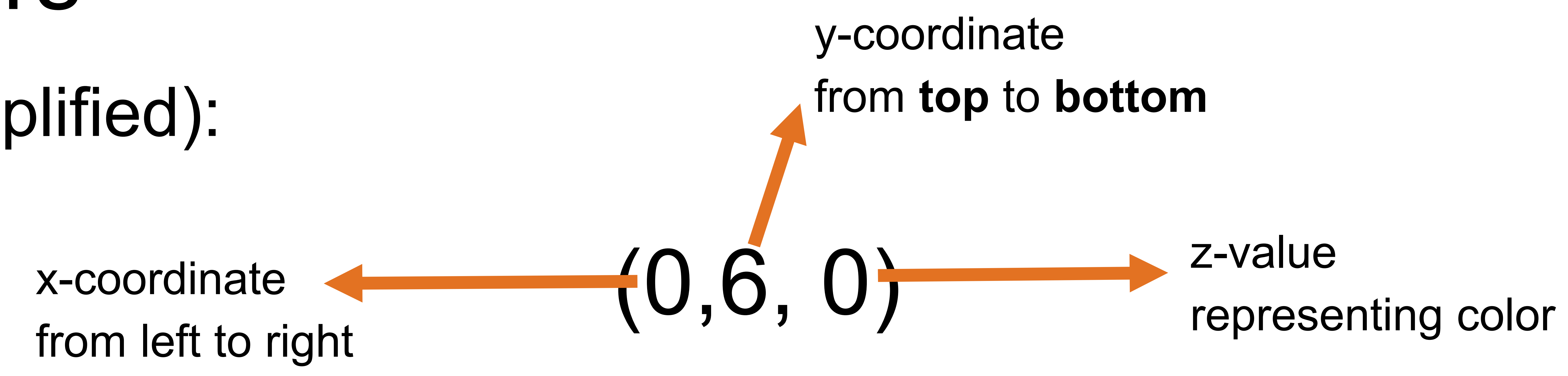


https://de.wikipedia.org/wiki/Datei:Punktdichte%2BFarbtiefe.svg

Image Parameters

Content of fish.jpg (simplified):

(0,0, 1)
(0,1, 1)
(0,2, 1)
…
(0,6, 0)
(0,7, 1)
…



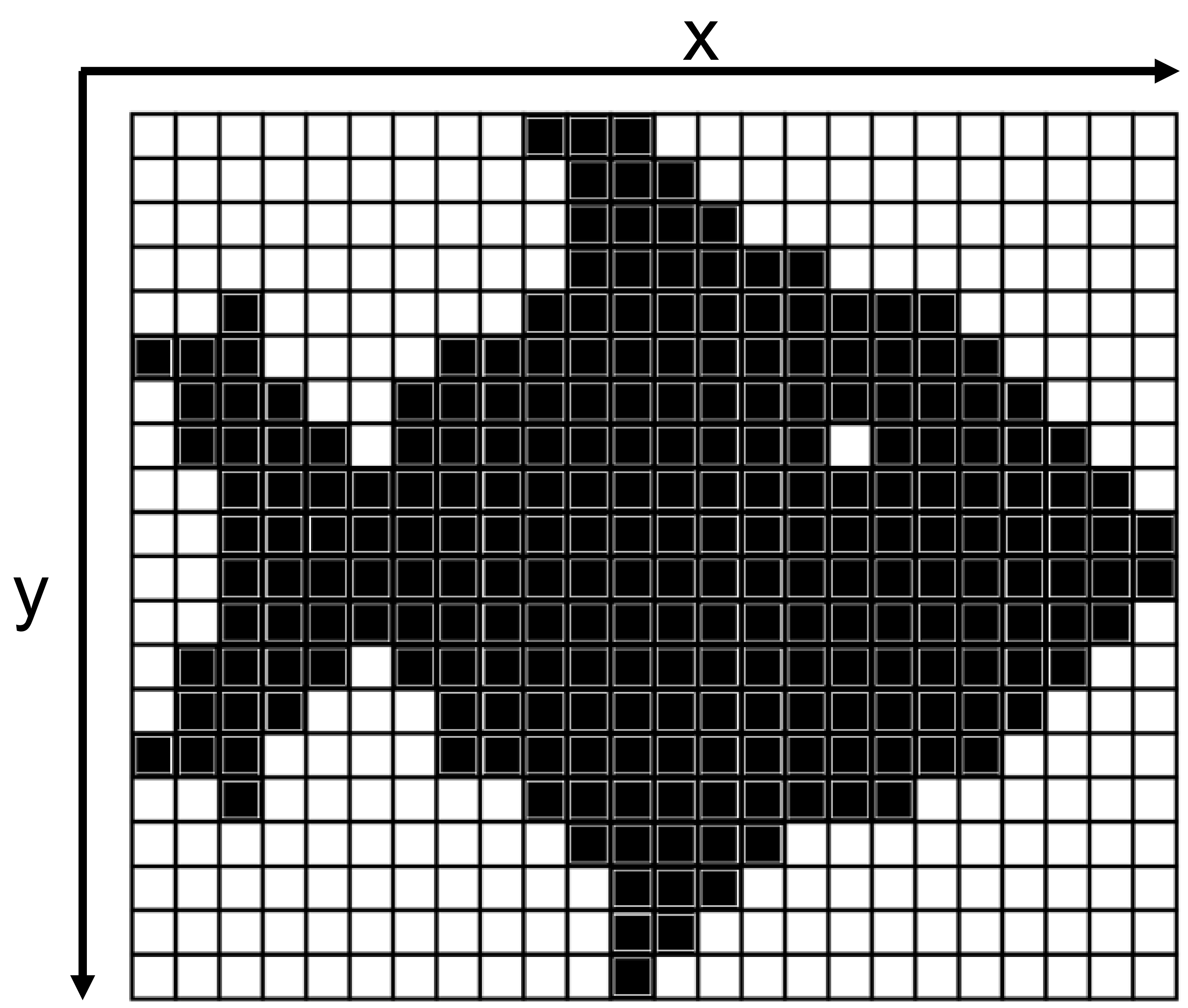


Image Parameters:

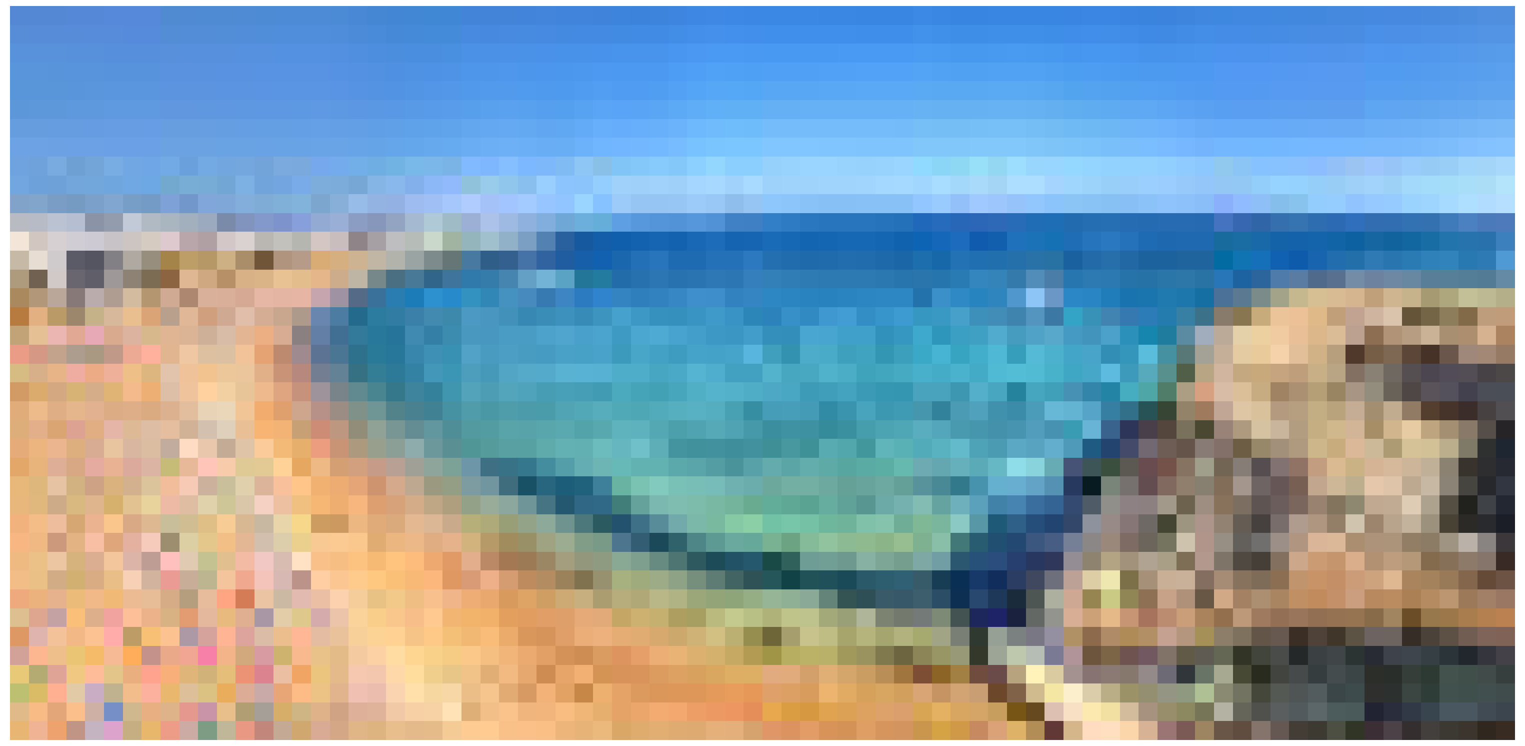
- A *pixel* is the smallest unit of an image. Size of pixel depends on output device.
- Pixel aspect ratio (not necessarily 1)
- Image size in number of pixels (e.g. 24x24 pixels)
- Image resolution: number of pixels available on a distance
  - *pixels per inch (ppi)*
  - 1 in = 2.54 cm
  - Standard resolution for displays: 72ppi
  - Typical value for print: 300ppi
- Dimension /Resolution / Pixel size:
  width [px] = width [in] * resolution [ppi]

Resolution of Digital Images

x-resolution: 1280 px

320px

160px



80px

https://commons.wikimedia.org/wiki/File:Albufeira_beach_portugal.jpg

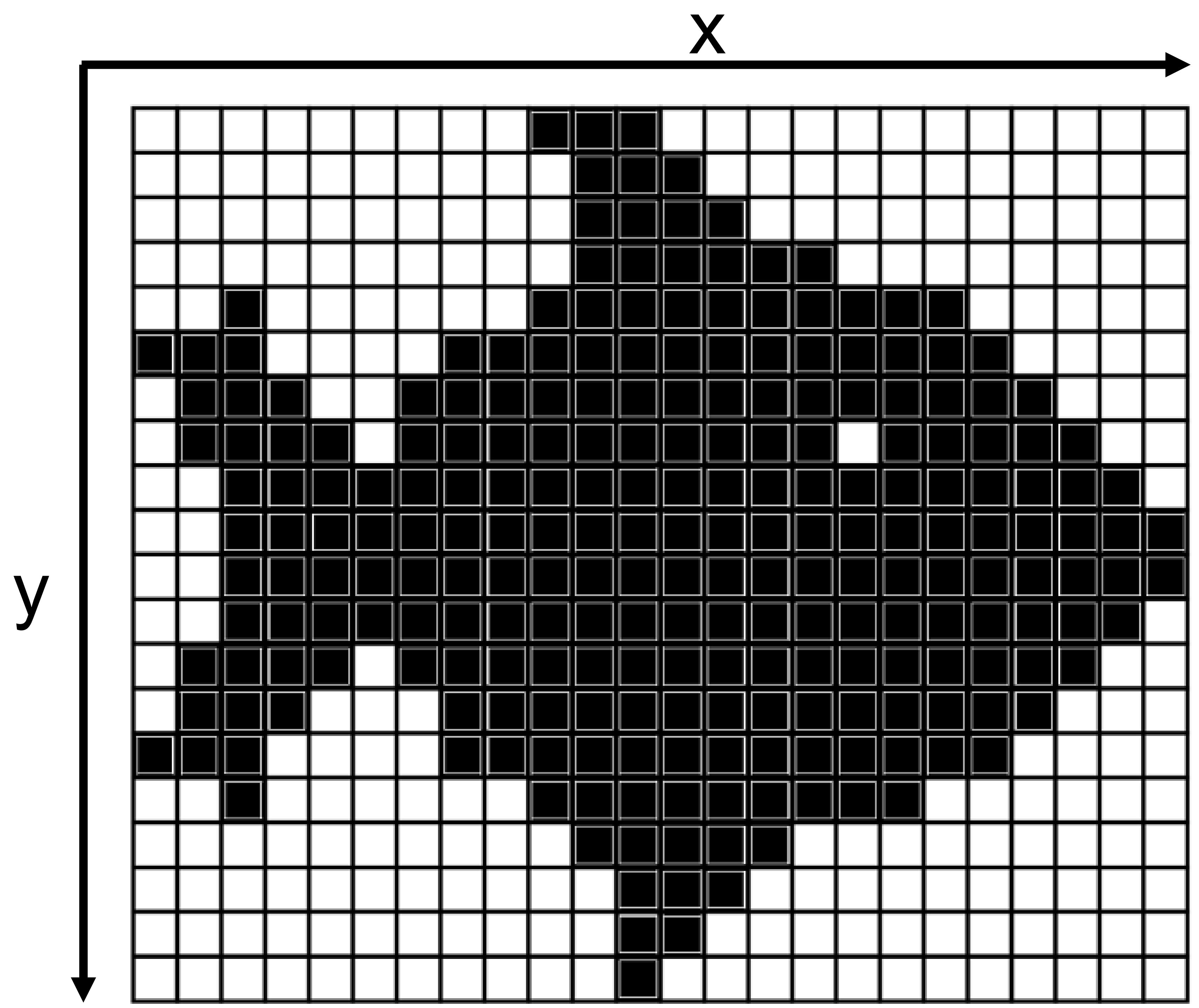
Color of Digital Images

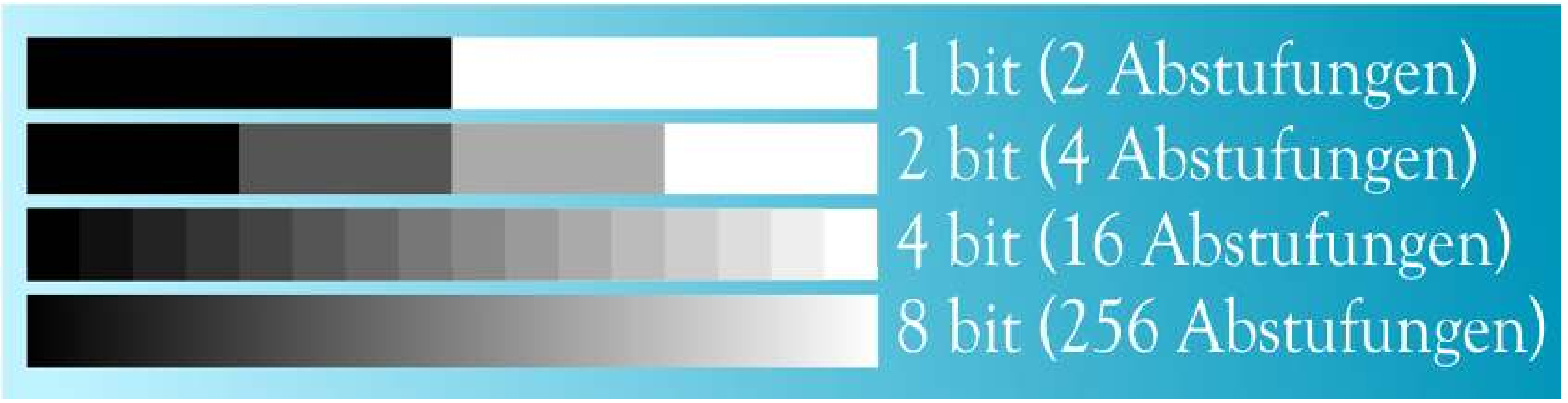
Content of fish.jpg (simplified):

(0,0, 1)
(0,1, 1)
(0,2, 1)
…
(0,6, 0)
(0,7, 1)
…

(0,6, 0)

Color Depth:
How many values are allowed here?



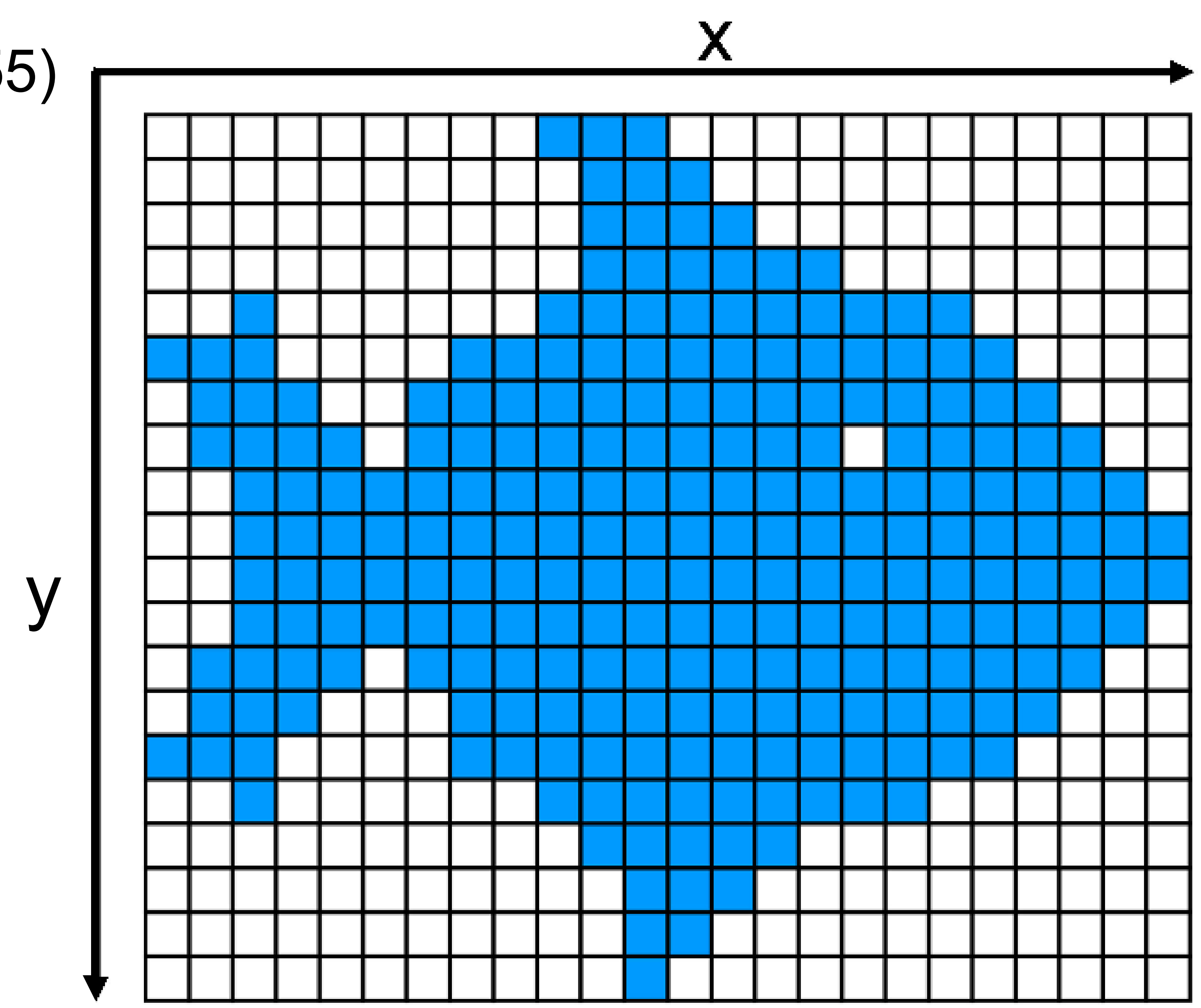


https://de.wikipedia.org/wiki/Datei:Farbtiefe.svg

Color of Digital Images

Content of fish.jpg (simplified):

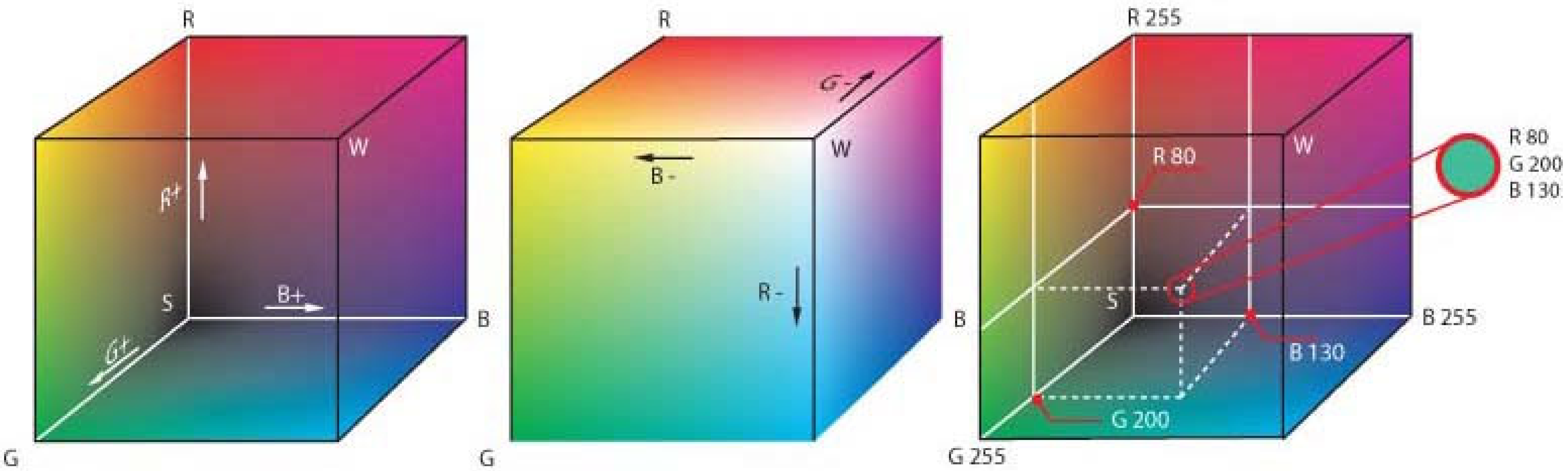
(0,0, 255,255,255)
(0,1, 255,255,255)
(0,2, 255,255,255)
…
(0,6, 0,153,254)
(0,7, 255,255,255)
…



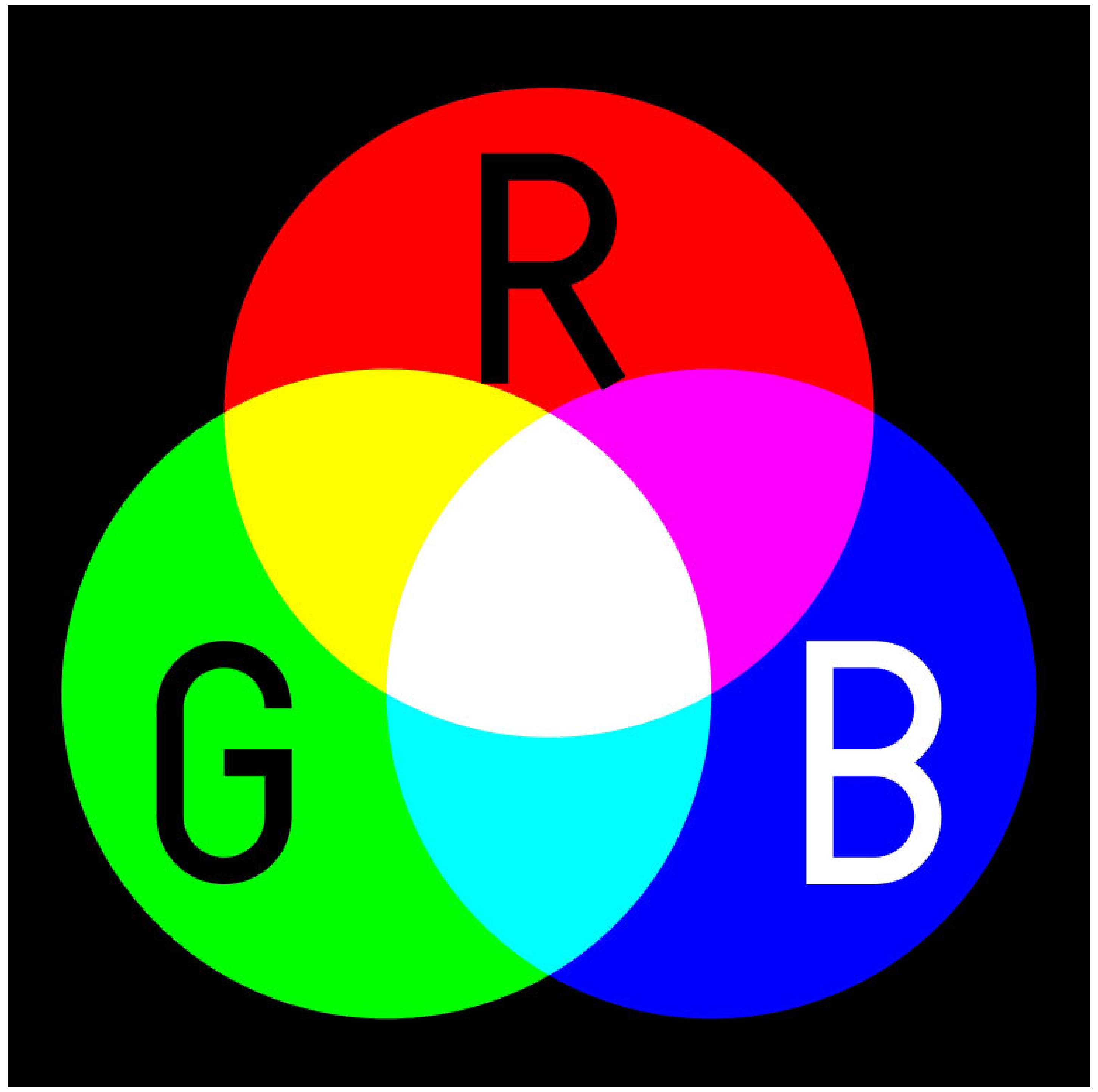
(0,6, 0,153,254)

RGB color tuple
Red
Green
Blue

RGB Color Space

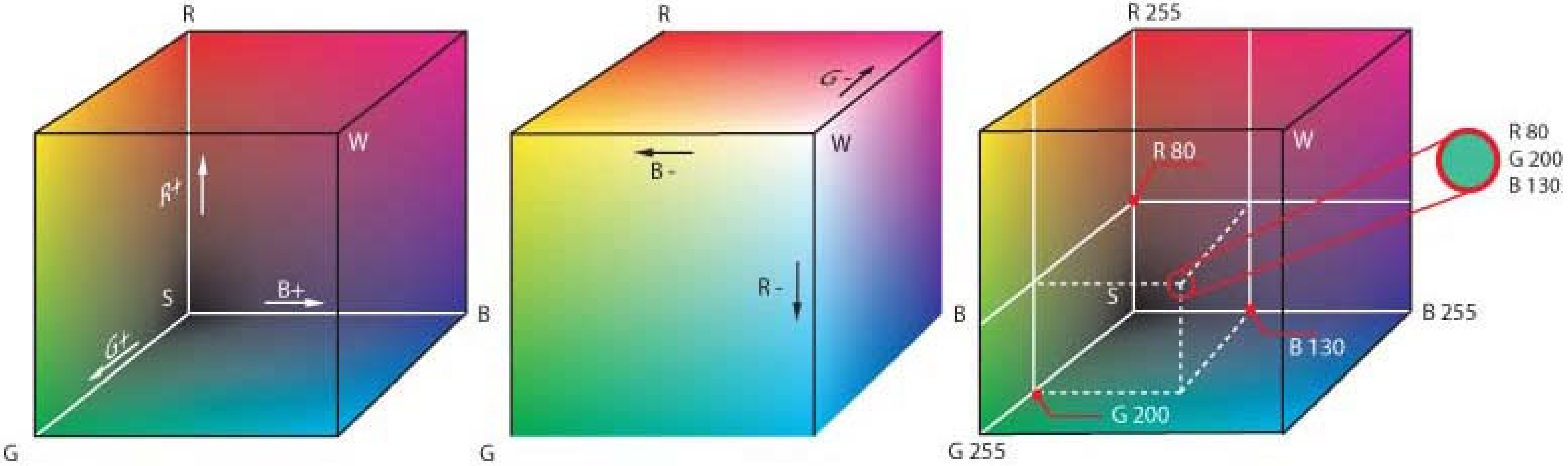


- Additive Color Model
  Spectral intensities are added together to produce a color
- For output mediums that actively produce light (e.g. displays)
- Device-dependent
- Some colors not representable within the RGB space



https://commons.wikimedia.org/wiki/File:RGB_farbwuerfel.jpg
https://en.wikipedia.org/wiki/RGB_color_model

RGB Color Space



Red
8 Bit
256 Values

Green
8 Bit
256 Values

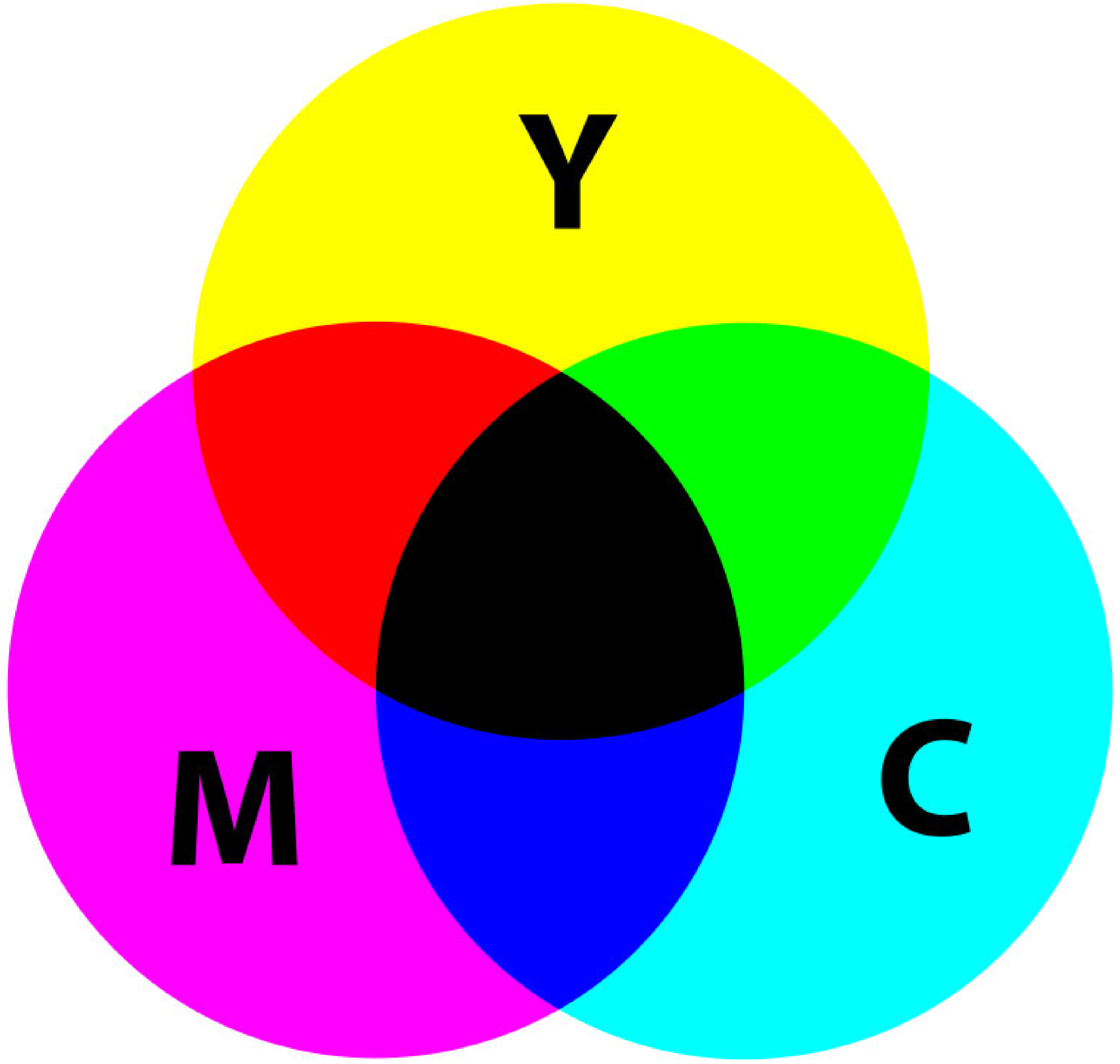
Blue
8 Bit
256 Values

24 Red
57 Green
102 Blue

https://commons.wikimedia.org/wiki/File:RGB_farbwuerfel.jpg

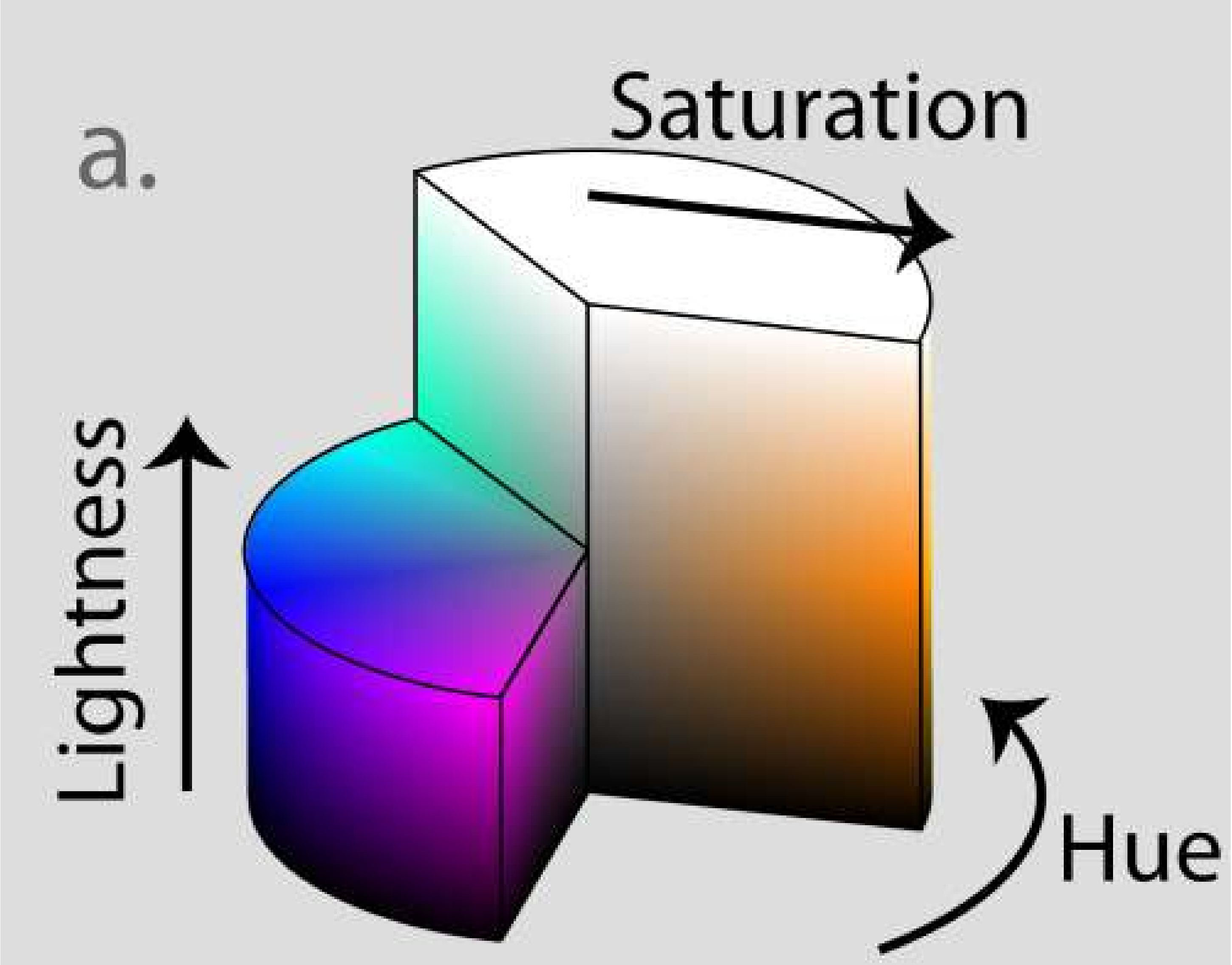
CMYK Color Space

- Subtractive Color Model:
  White is the natural color of the paper and color “reduces whiteness”
- Mainly used for printing
- Think of color filters
- For printing, **K** represents a blacK component – mainly to save ink

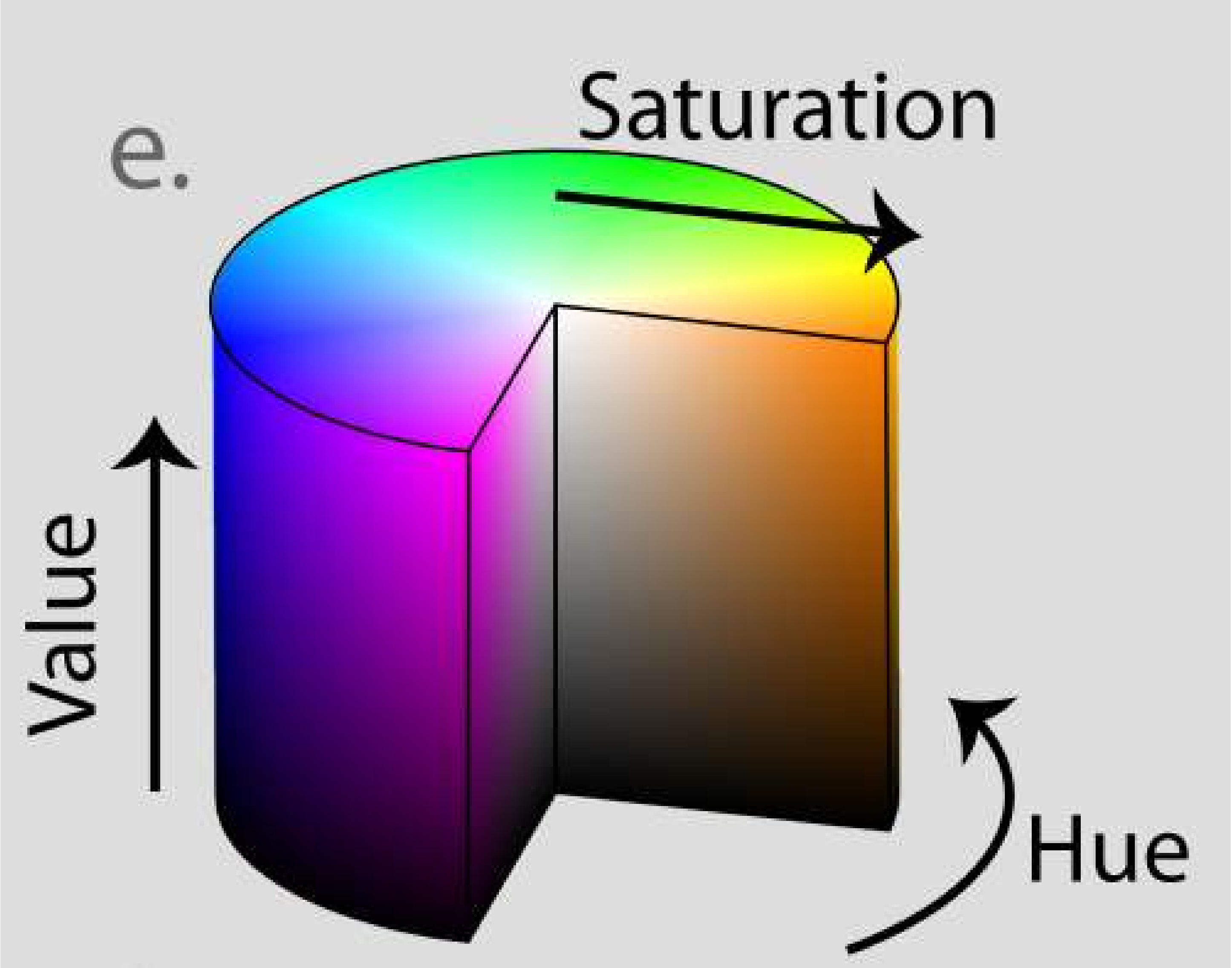


https://en.wikipedia.org/wiki/CMYK_color_model

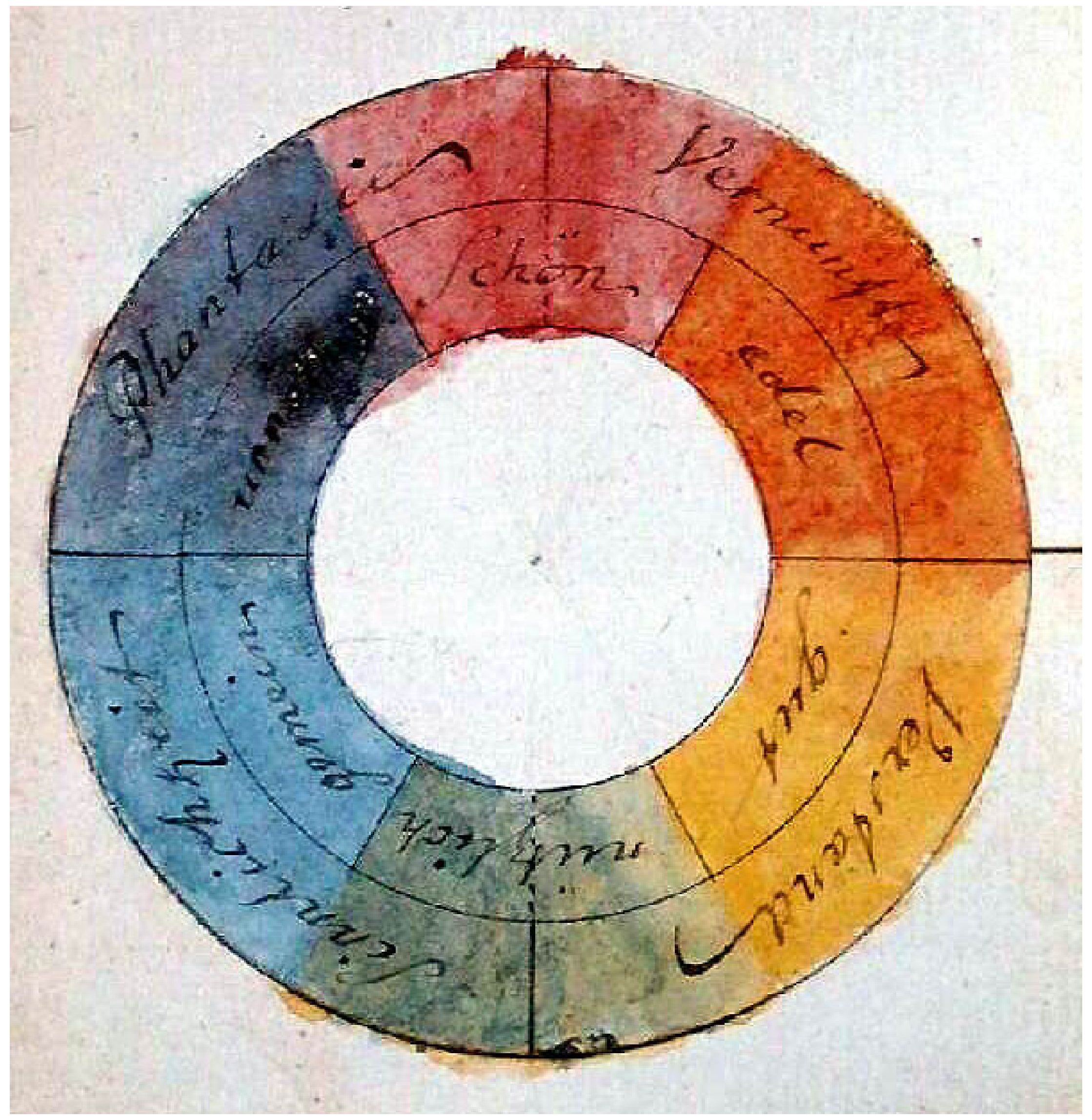
Other Color Spaces



HSL:
Hue, Saturation, Lightness



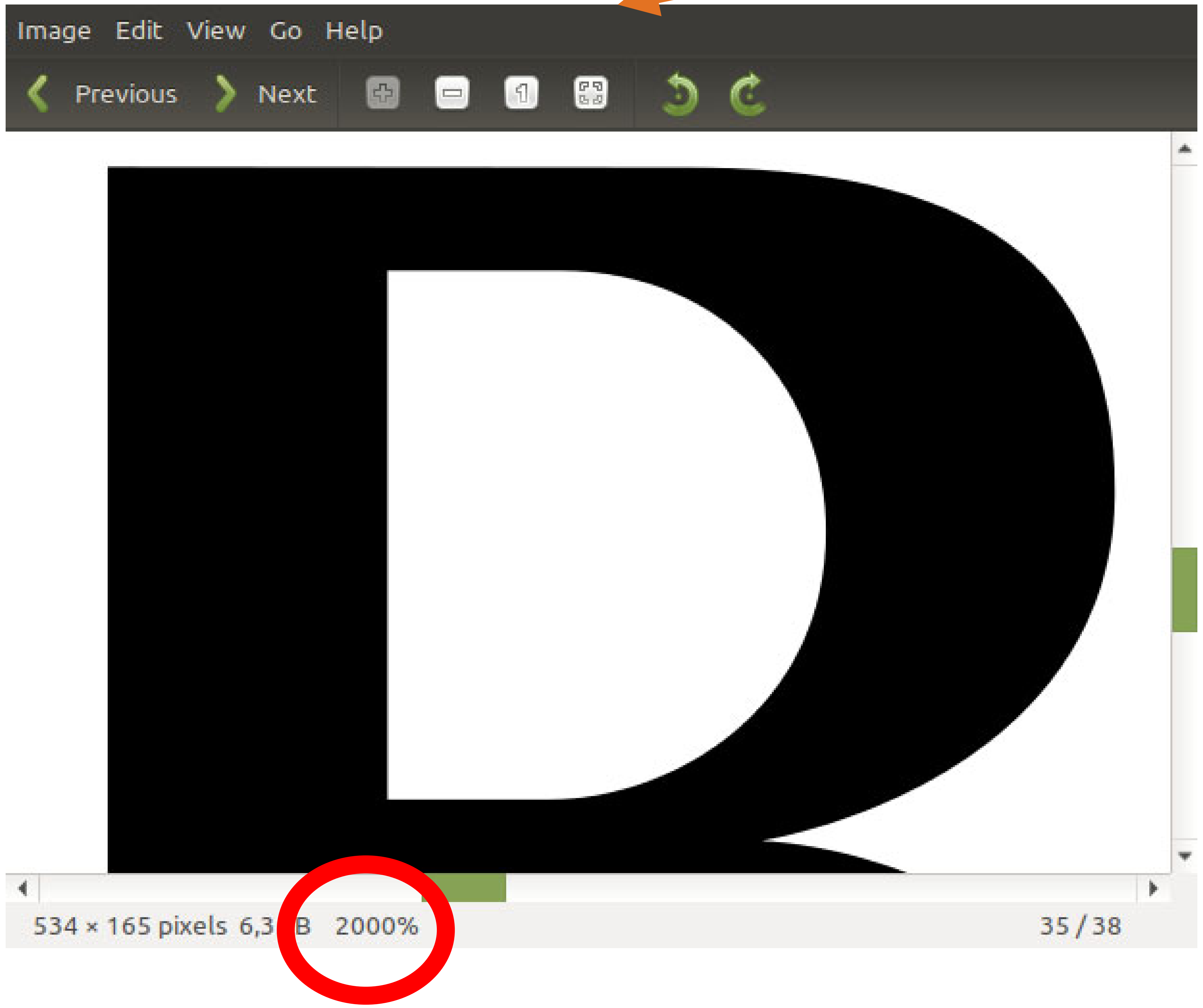
HSV:
Hue, Saturation, Value

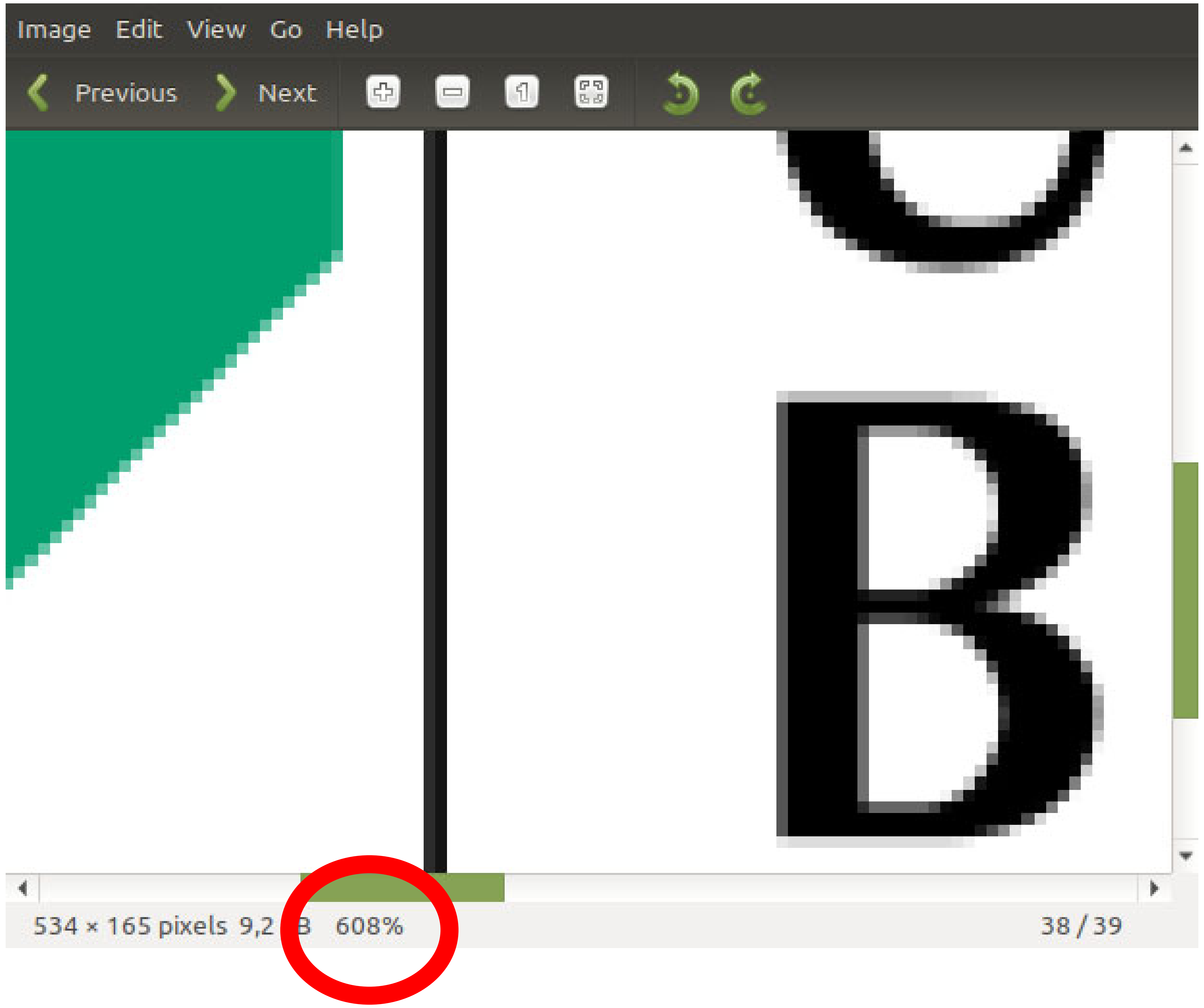


Goethe’s Color Wheel

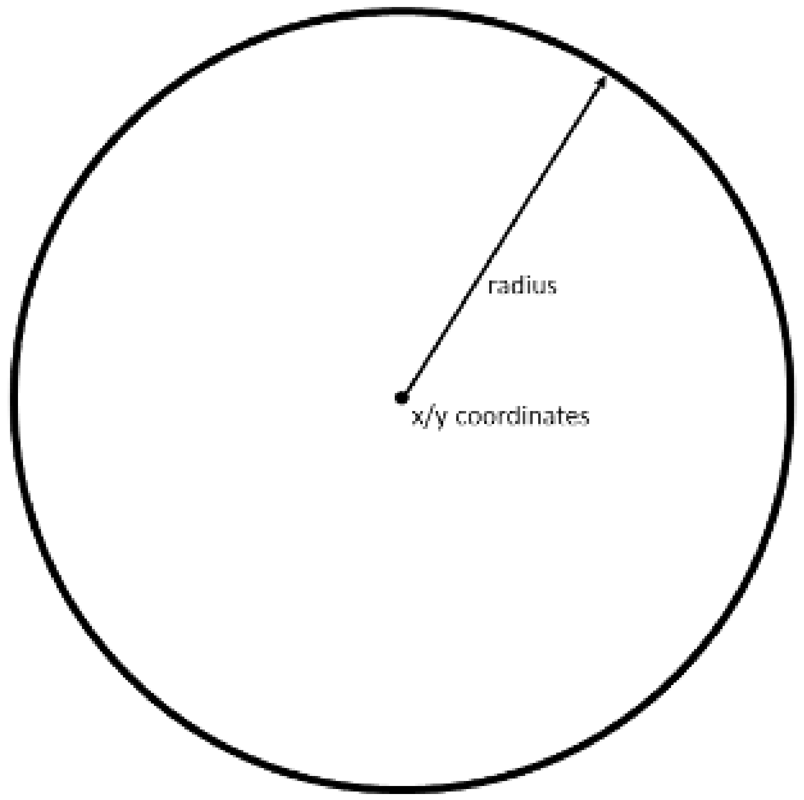
https://en.wikipedia.org/wiki/Theory_of_Colours

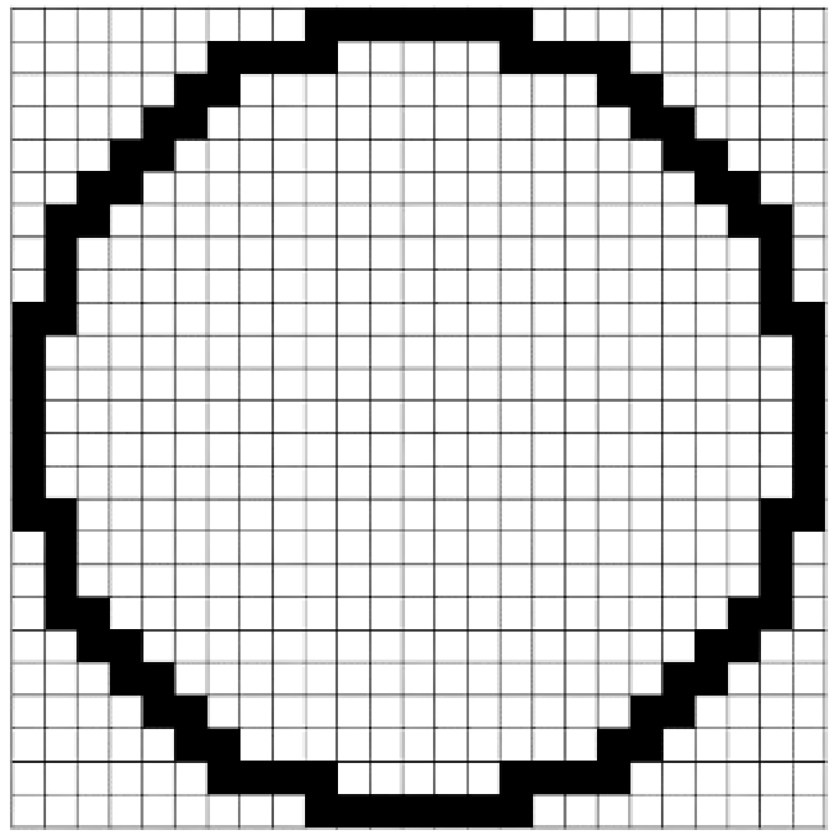
Raster vs. Vector Graphics





Raster vs. Vector Graphics





Vector Graphics:

Image is stored as geometric description
Scales infinitely
Small files
Great for web images, illustrations, logos, technical drawings

Raster Graphics:

Image is stored as a matrix of pixels - max. resolution fixed
Does not scale
Large files
Great for photographs

SVG: Scalable Vector Graphics

```
<svg viewBox="0 0 100 100" xmlns="http://www.w3.org/2000/svg">
  <circle cx="50" cy="50" r="50"/>
</svg>
```

Example SVG file

Digital Text

Text on Images

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If text is digitized using a scanner, it ends up as a raster graphic.

Problem:

For the computer, this is only a matrix of pixels, e.g. color values

It is not processable as text, e.g.:

- it can’t be indexed, i.e. used for search & discovery
- it can’t be used for tasks of Natural Language Processing (e.g. counting words, describing the vocabulary, …)
- it takes up much more disk space for archiving than a representation as text

> Optical character recognition or optical character reader is the electronic or mechanical conversion of images of typed, handwritten or printed text into machine-encoded text, whether from a scanned document, a photo of a document, a scene-photo or from subtitle text superimposed on an image.

https://en.wikipedia.org/wiki/Optical_character_recognition

OCR: Two basic types

1. Matrix Matching

    aka pattern matching or pattern recognition

    Comparing an image of a character to stored glyphs pixel-by-pixel

    Works best with typewritten text:

    - Requires glyphs to be clearly isolated
    - Stored glyphs need to be in a similar font and in a similar scale

OCR: Two basic types

2. Feature Recognition

   based on machine-learning:

   Decompose glyphs into “features” like lines, closed loops, line direction, and line intersections

   Describe glyphs by abstract representations, i.e. numeric vectors that express the features mathematically

   Compare features to abstract representations of glyphs by comparing vectors, e.g. find the most similar match

Helping the computer: two crucial steps before OCR

1. **Preprocessing**
   1. Binarization
   2. Skew Correction
   3. Noise Removal
   4. Thinning and Skeletonization (only for handwritten text)
2. **Segmentation**
   1. Layout-Analysis
   2. Line-level Segmentation
   3. Word-level Segmentation
   4. Character-level Segmentation

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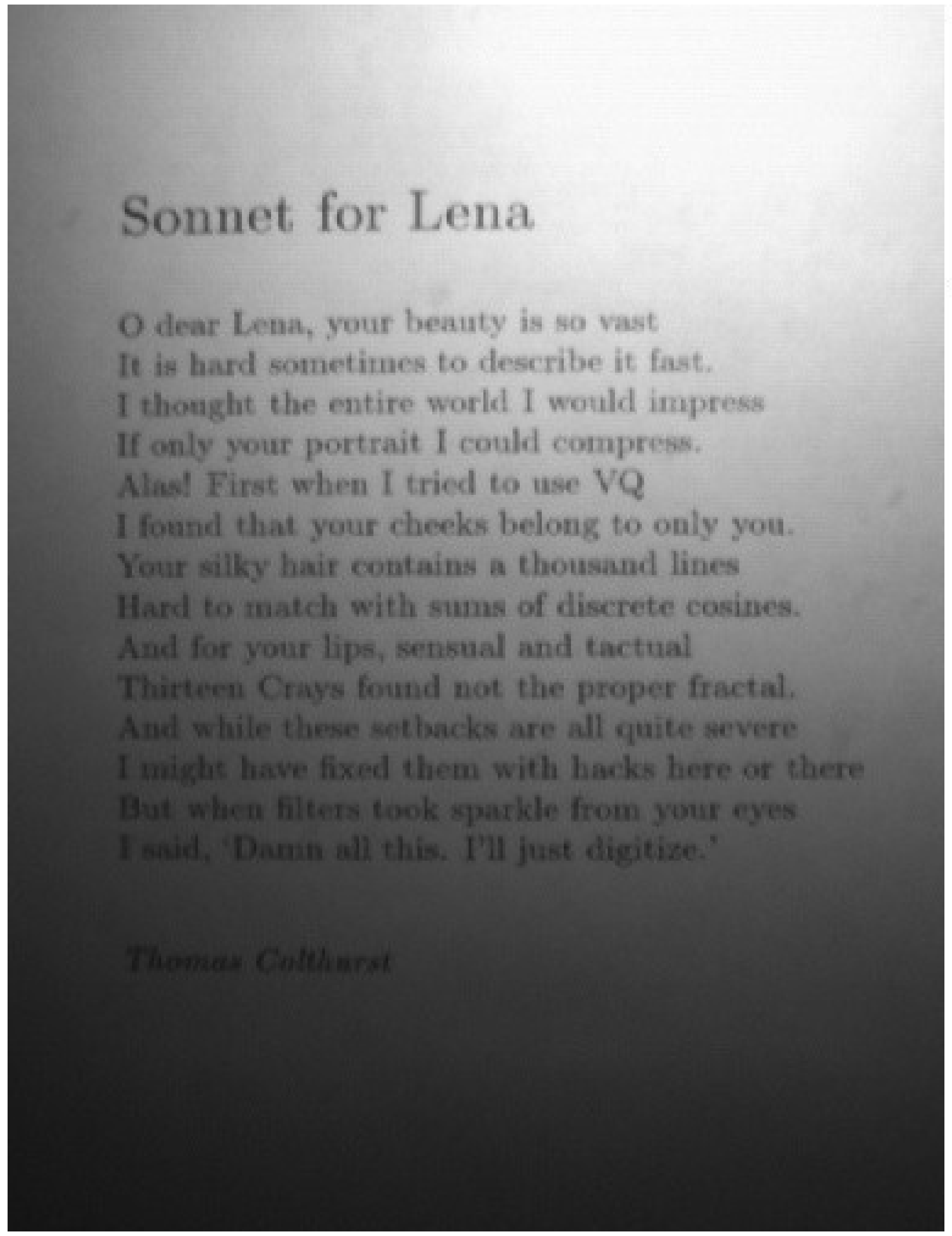
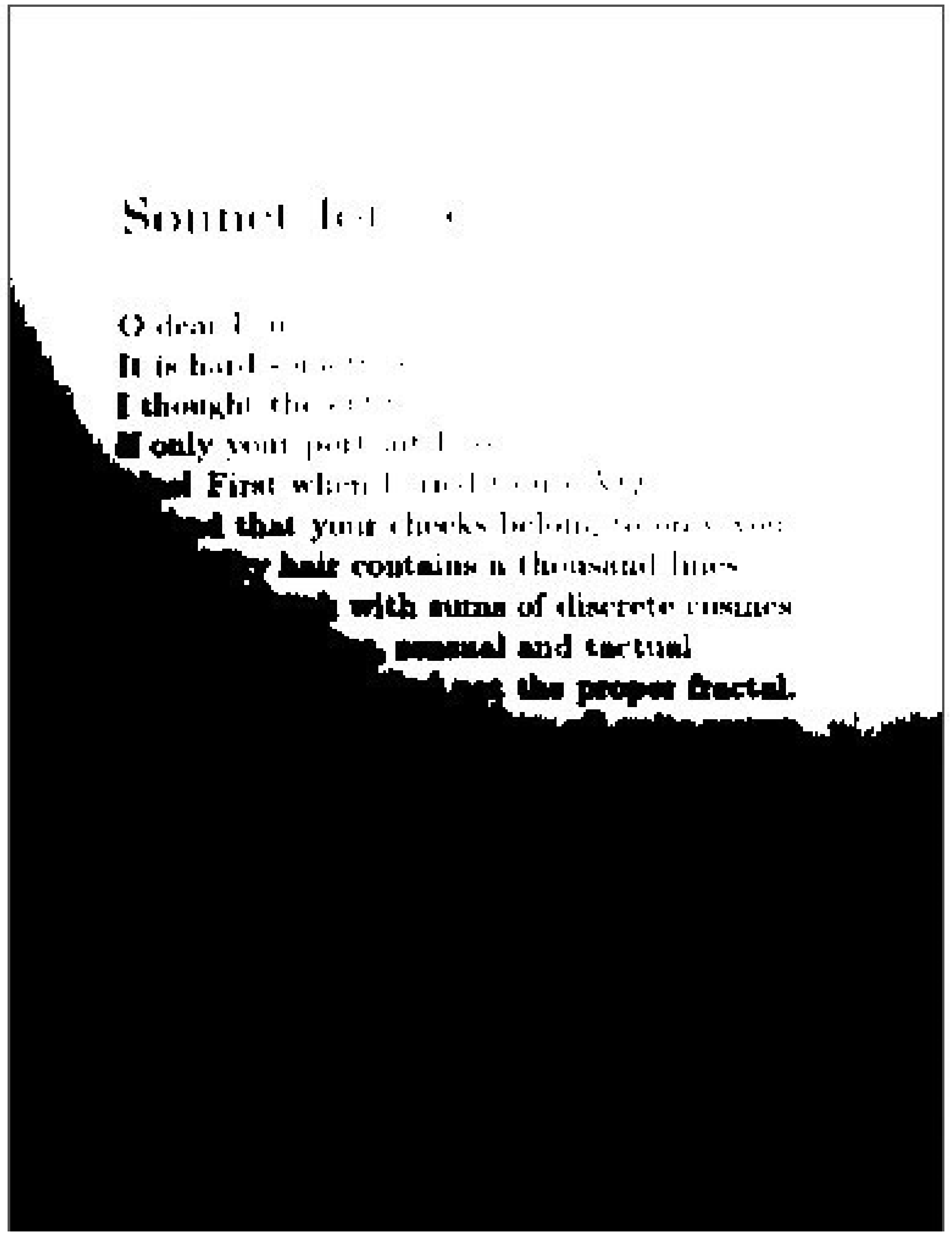


Sonnet for Lena

O dear Lena, your beauty is so vast
It is hard sometimes to describe it fast.
I thought the entire world I would impress
If only your portrait I could compress.
Alas! First when I tried to use VQ
I found that your cheeks belong to only you.
Your silky hair contains a thousand lines
Hard to match with sums of discrete cosines.
And for your lips, sensual and tactual
Thirteen Crays found not the proper fractal.
And while these setbacks are all quite severe
I might have fixed them with hacks here or there
But when filters took sparkle from your eyes
I said, 'Damn all this. I'll just digitize.'

Thomas Colthurst



https://towardsdatascience.com/pre-processing-in-ocr-fc231c6035a7

Helping the computer: two crucial steps before OCR

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   3. Word-level Segmentation
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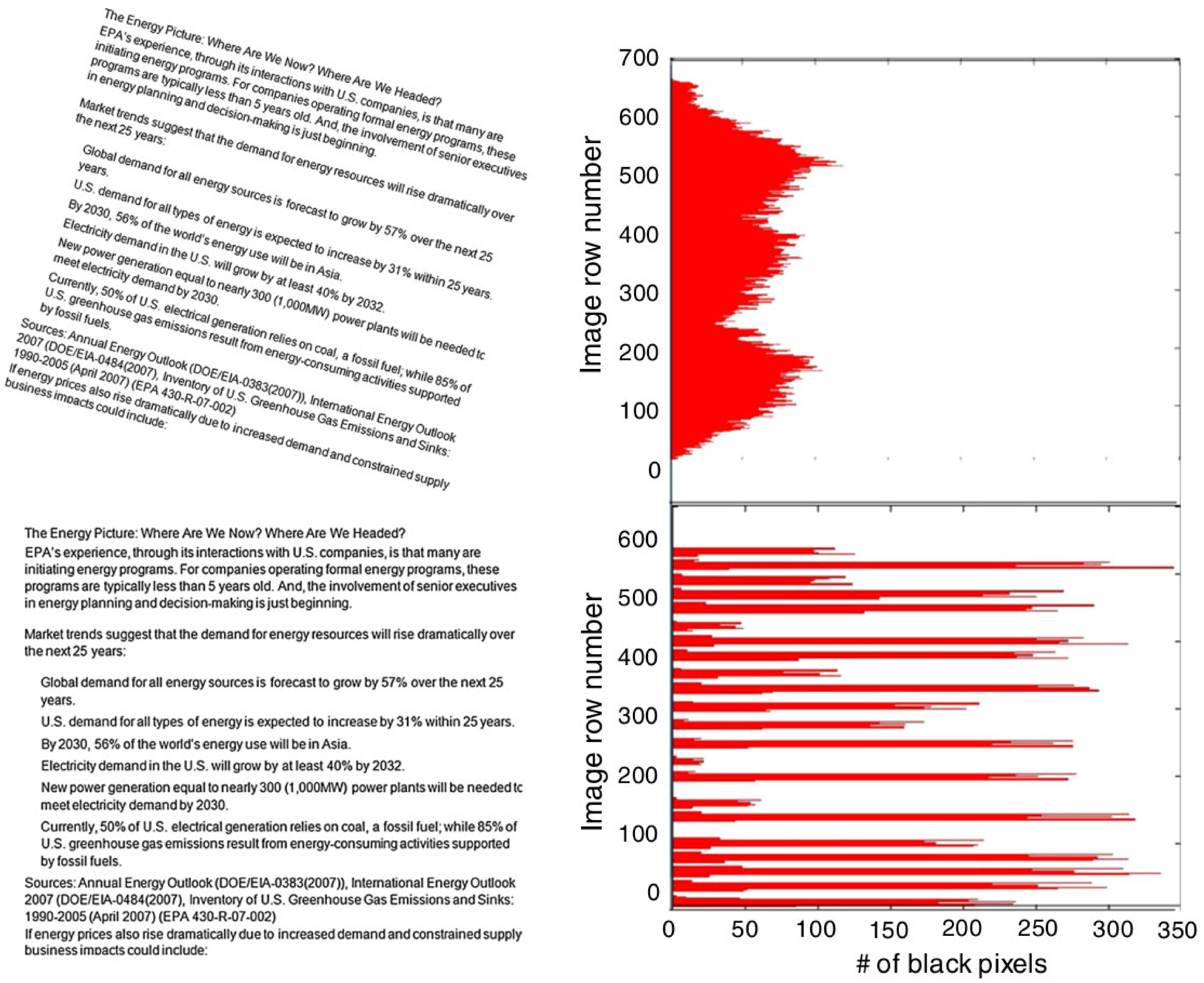

Shafii, M., & Sid-Ahmed, M. (2015). Skew detection and correction based on an axes-parallel bounding box. International Journal on Document Analysis and Recognition (IJDAR), 18(1), 59-71.

Helping the computer: two crucial steps before OCR

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https://towardsdatascience.com/pre-processing-in-ocr-fc231c6035a7

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Choudhary, A., Rishi, R., & Ahlawat, S. (2013). A new character segmentation approach for off-line cursive handwritten words. Procedia Computer Science, 17, 88-95.

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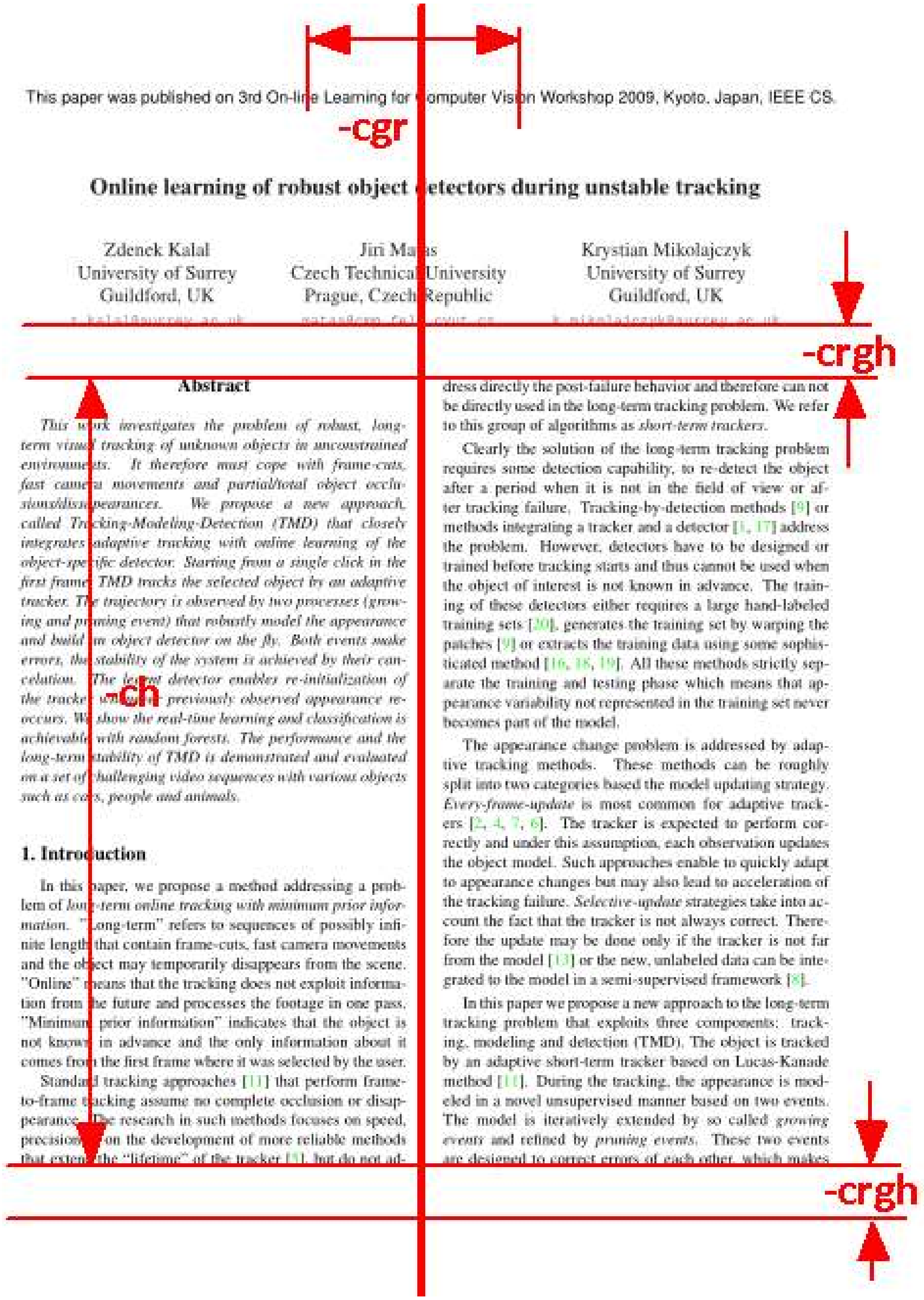

https://www.willus.com/k2pdfopt/help/columns.shtml

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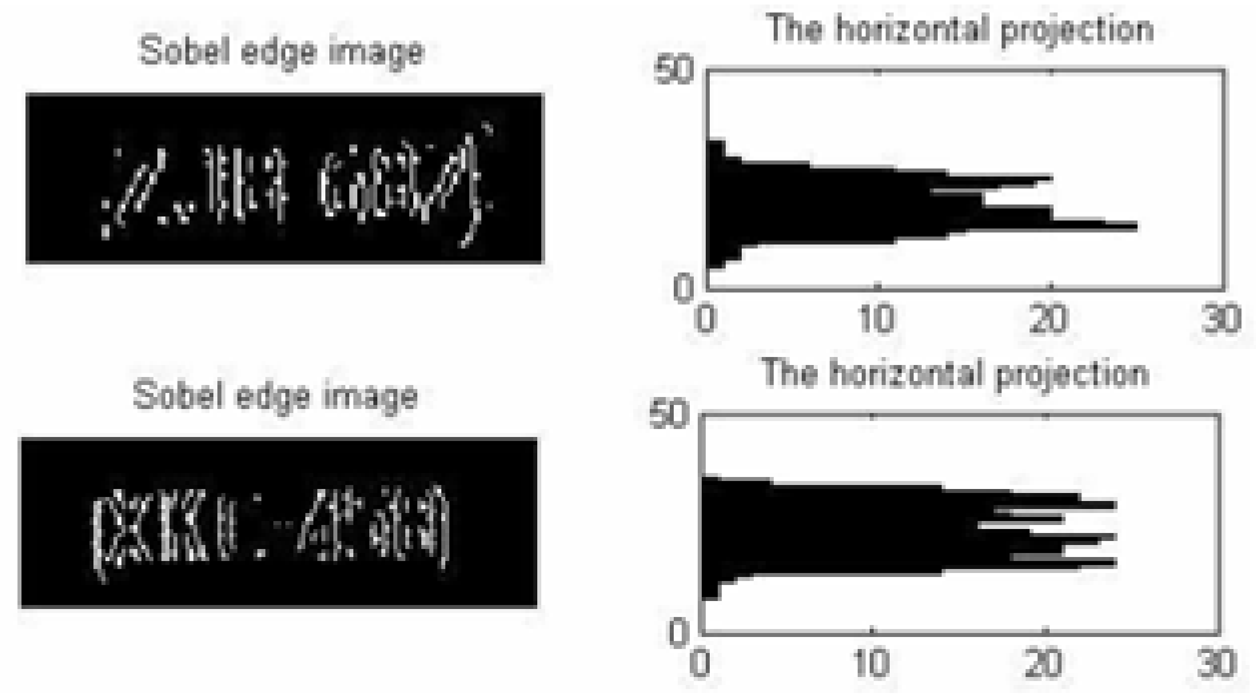

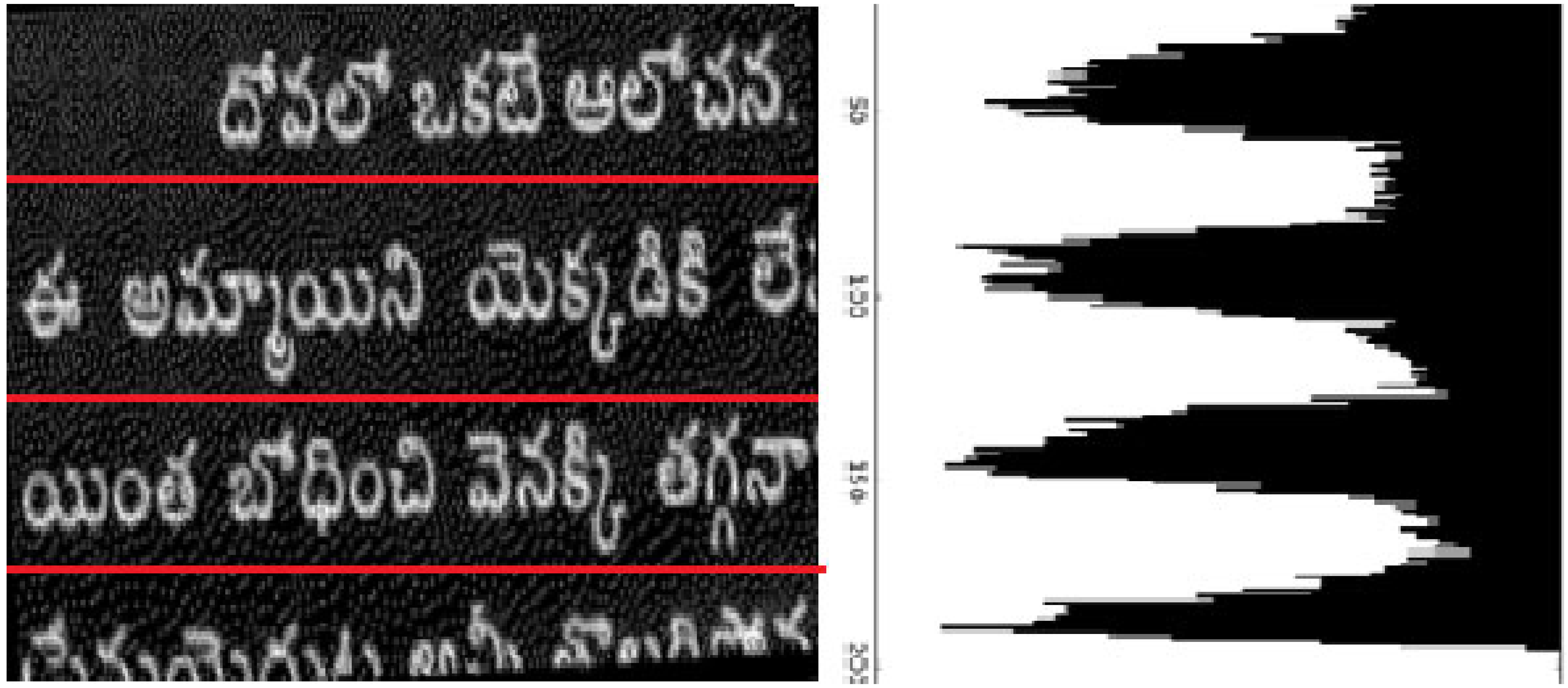

https://towardsdatascience.com/segmentation-in-ocr-10de176cf373

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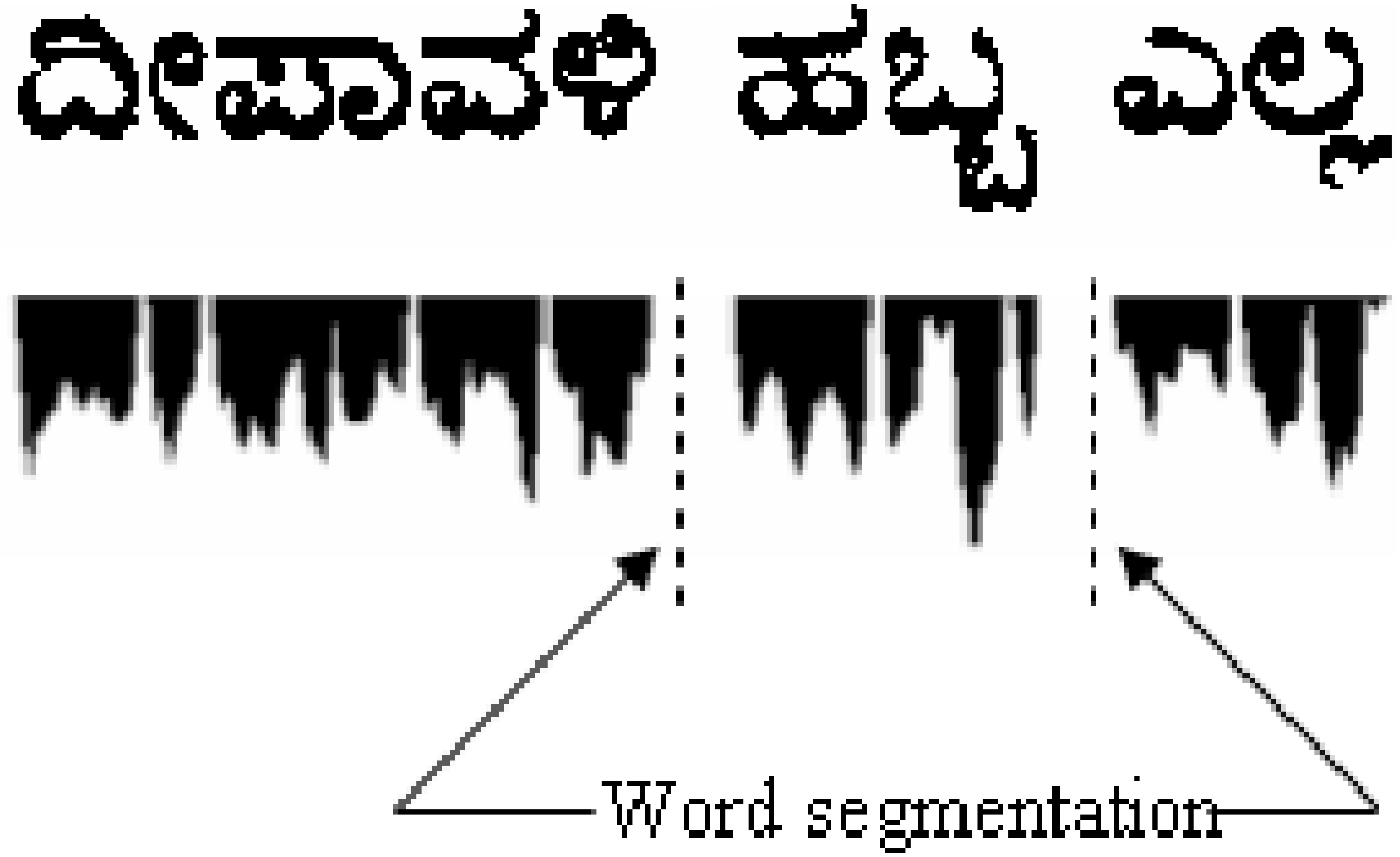

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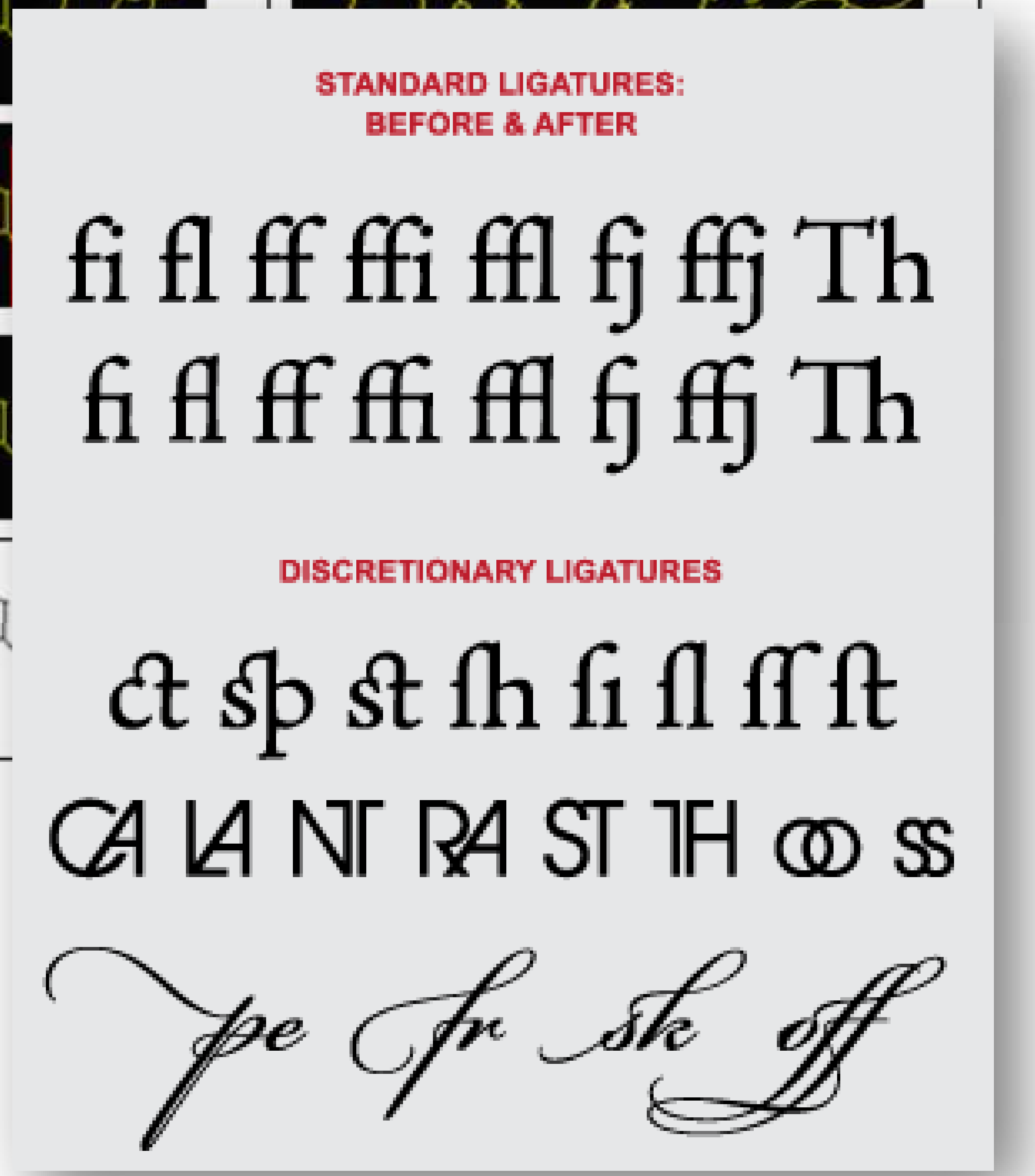

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https://www.fonts.com/content/learning/fyti/situational-typography/type-terms-a-trio-of-slightly-tricky-pairs

Helping the computer: what to do after OCR

- Dictionary-based approach

  Replace words by most likely words in a dictionary

  Decision of requiring a replacement is based on a distance metric between words, e.g. Damerau-Levenshtein distance, an edit distance expressing the number of operations (insertions, deletions, substitutions of characters) required to turn one word into another

  Medical Mÿstory ⇨ Medical Mystery

- Context-based approach

  Based on Statistical Language Modeling, e.g. modeling the probabilities of sequences of characters

  Statistical distributions of word associations in character sequences

  Takes context into account

  Medical Mÿstory ⇨ Medical History

https://medium.com/@techcapper/how-to-improve-ocr-accuracy-124d2ebe0cd2

OCR Accuracy

Character Accuracy	Approach	Purpose
99,997%	Double keying with corrections	Editions
99,95%	Double keying	Negative Search
99%	OCR with near-perfect input	Text Mining
95%	OCR with good input	Positive Search

Thanks.

mirco.schoenfeld@uni-bayreuth.de