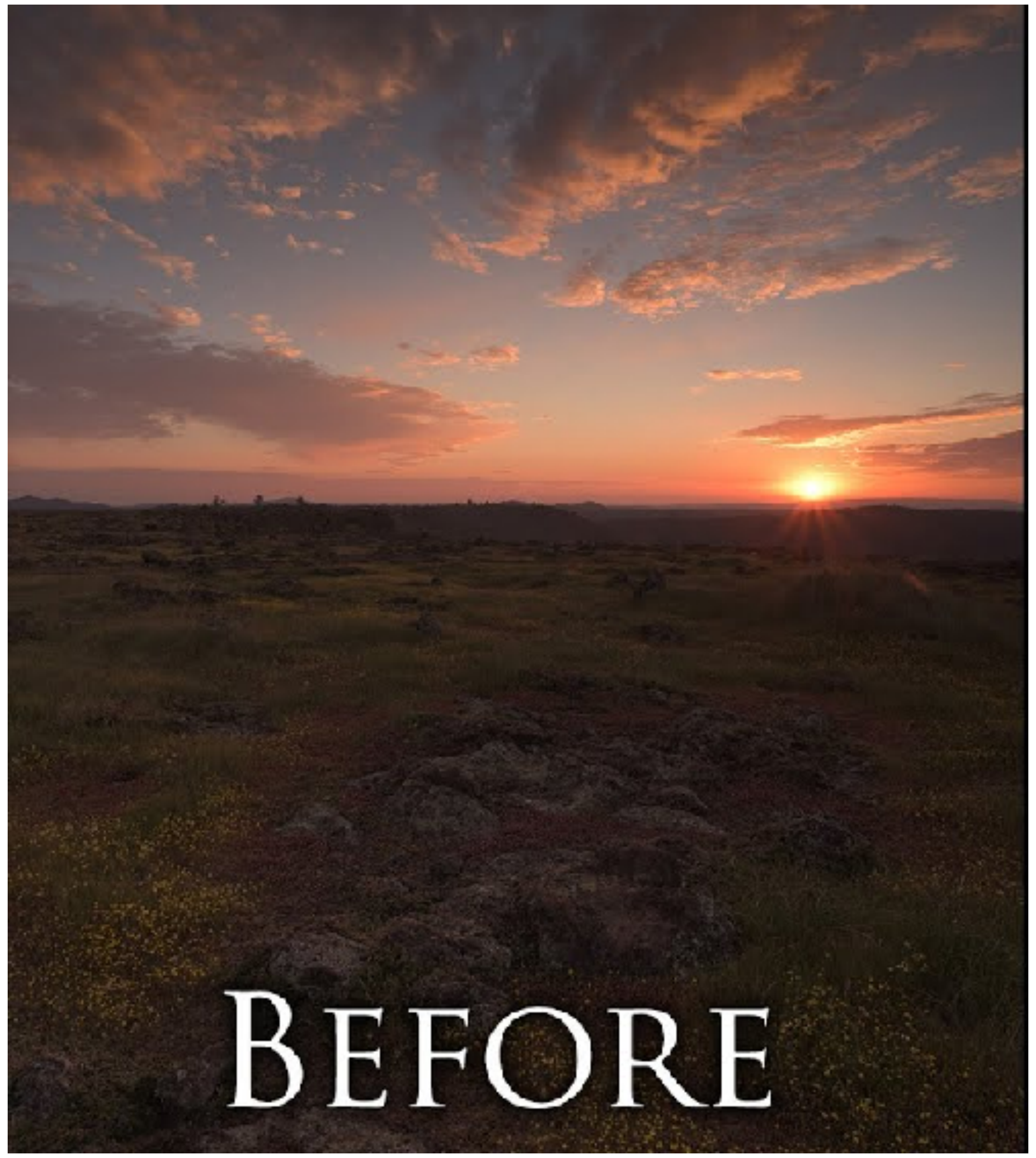
COMP0026: Image Processing

Introduction



UCL

COMP0026: Image Processing

Introduction

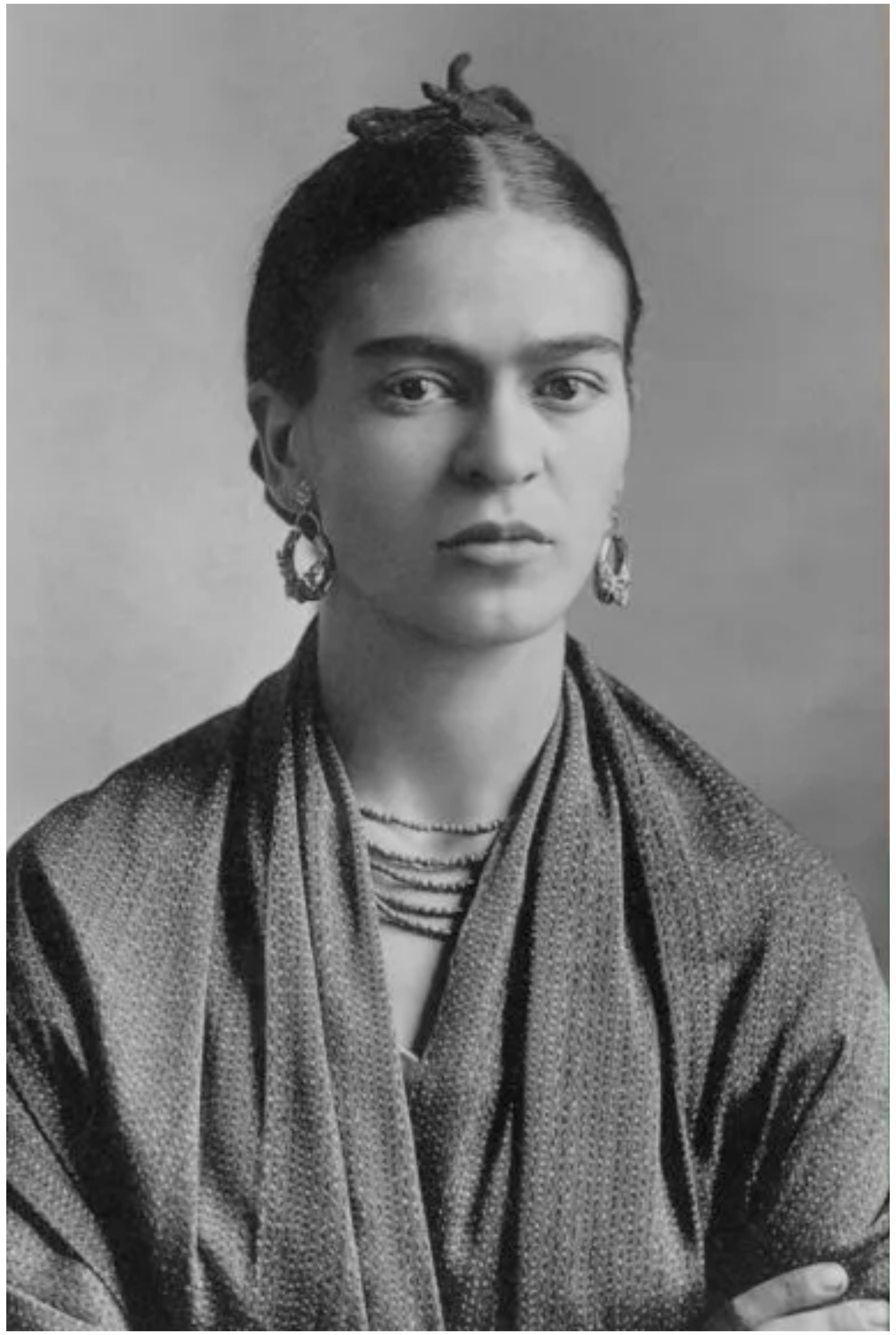
UCL

Lectures will be Recorded

Denoising

Denoising

Colorization



Colorization

Image Inpainting

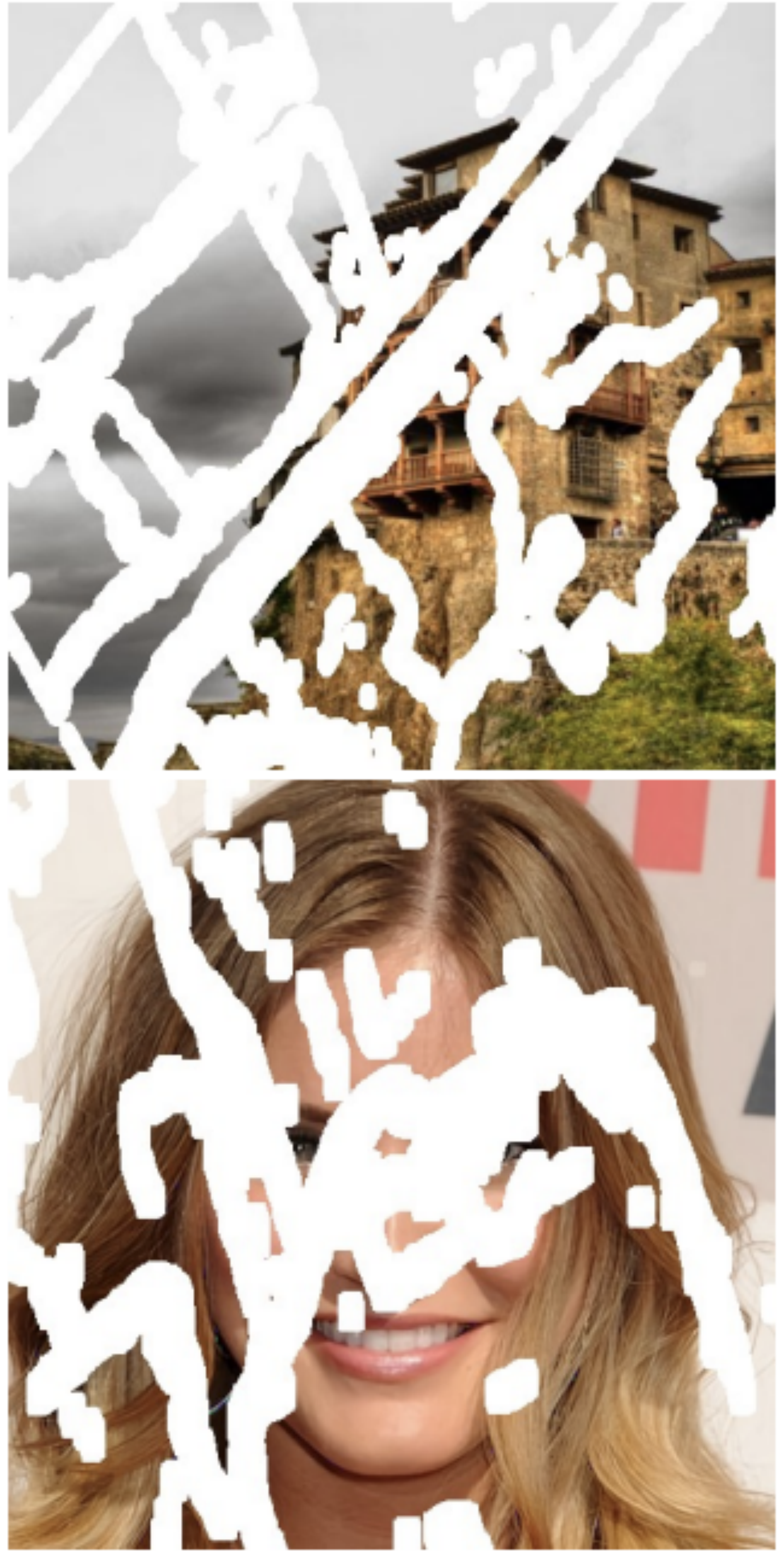


Image Inpainting

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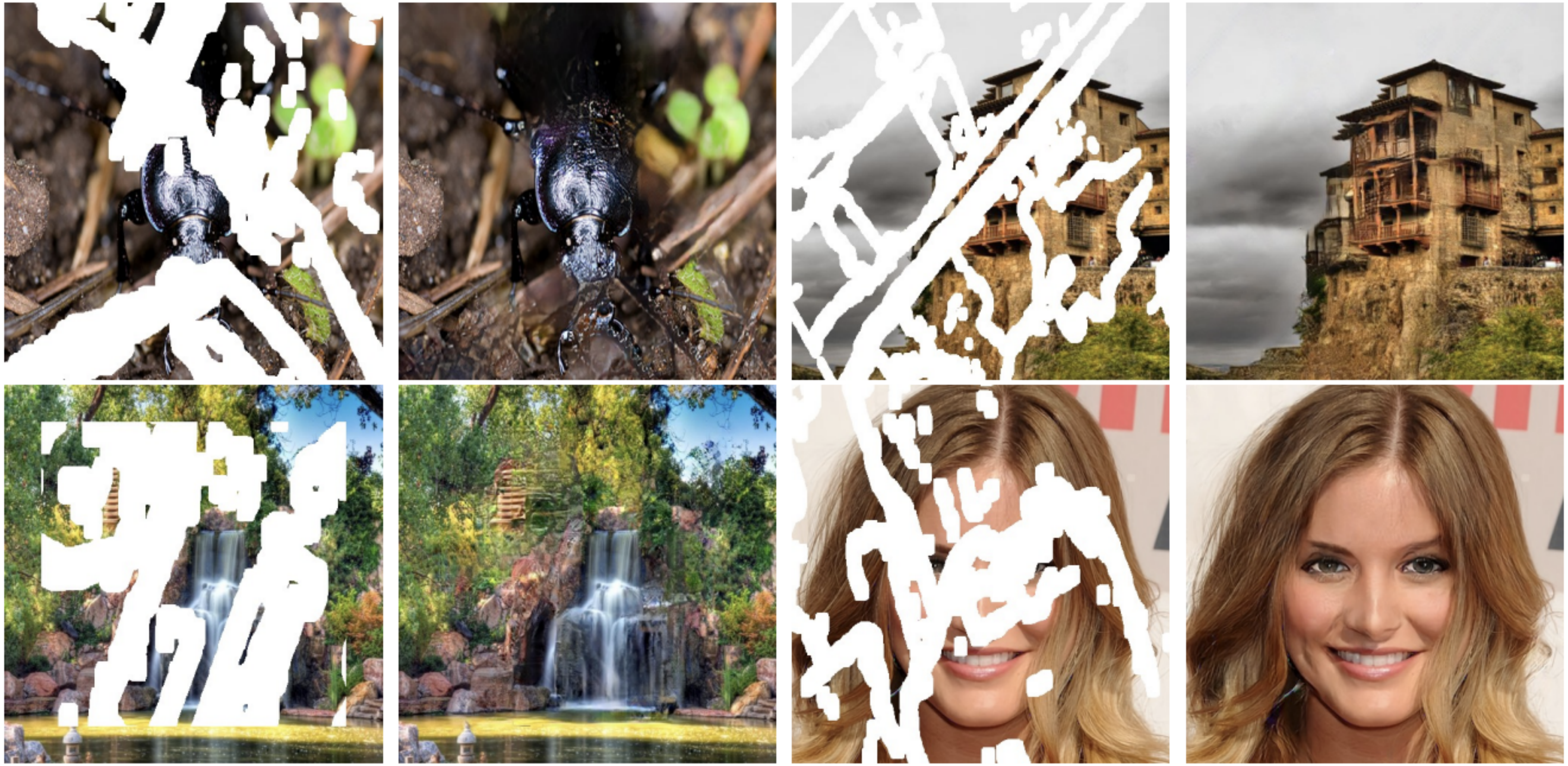
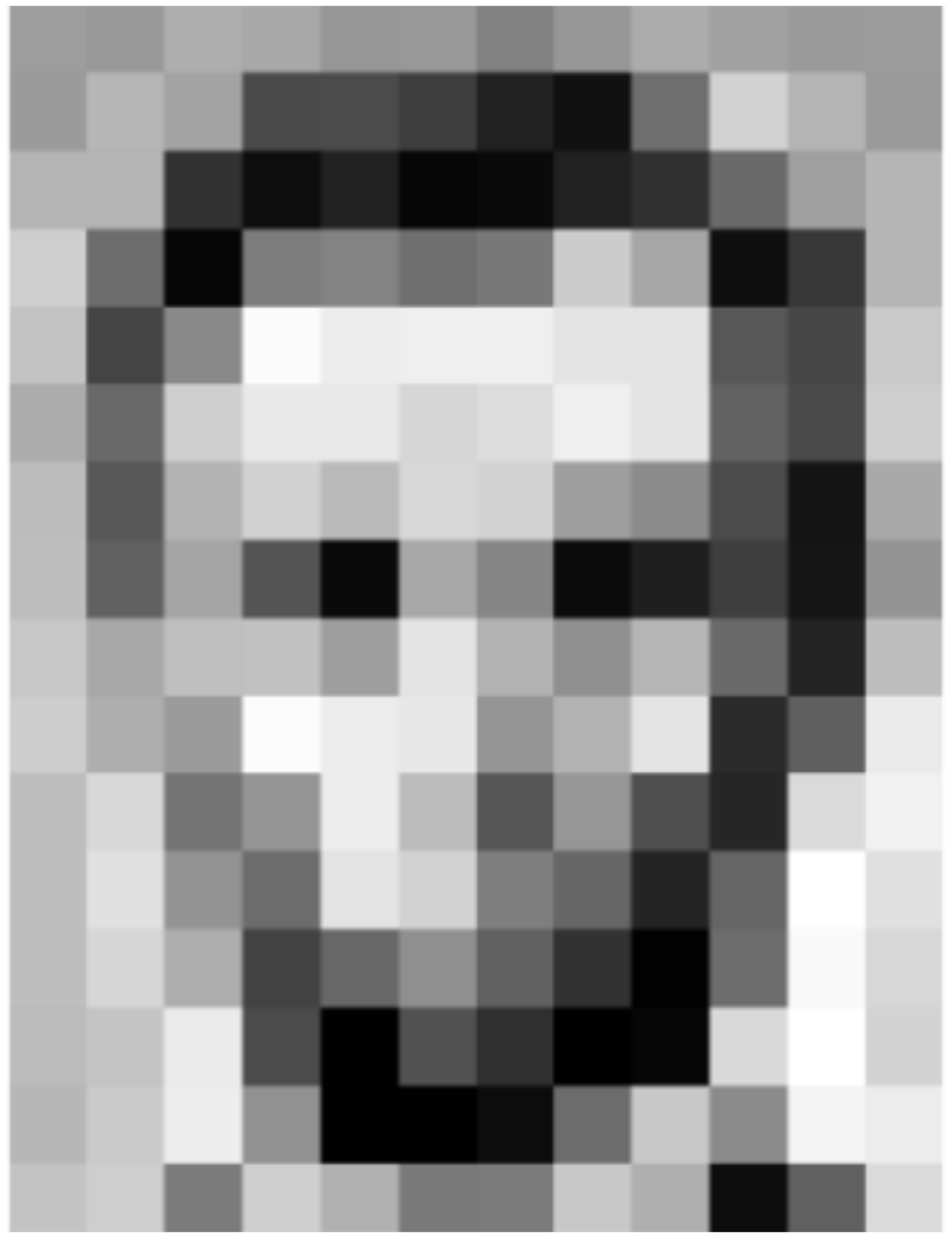
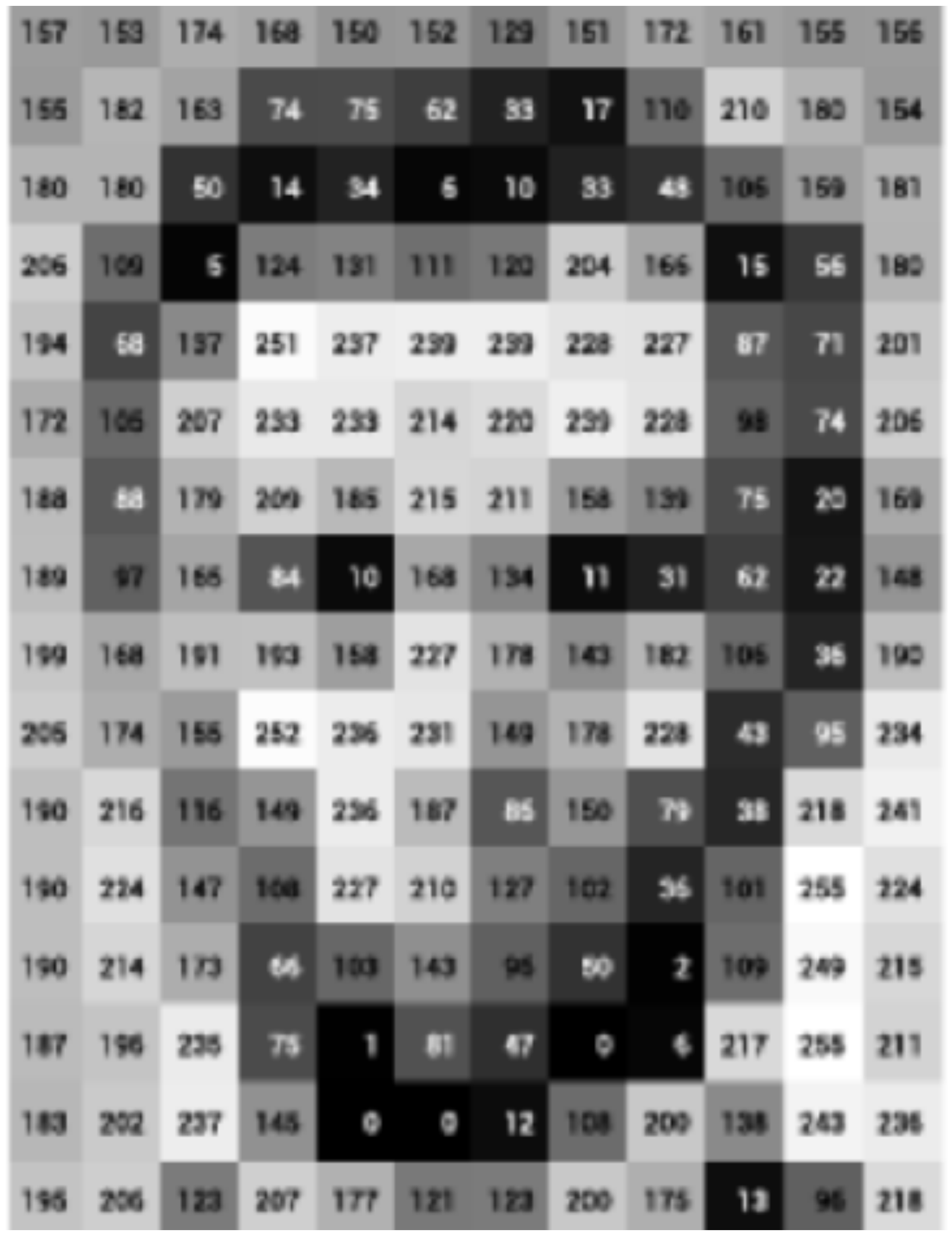


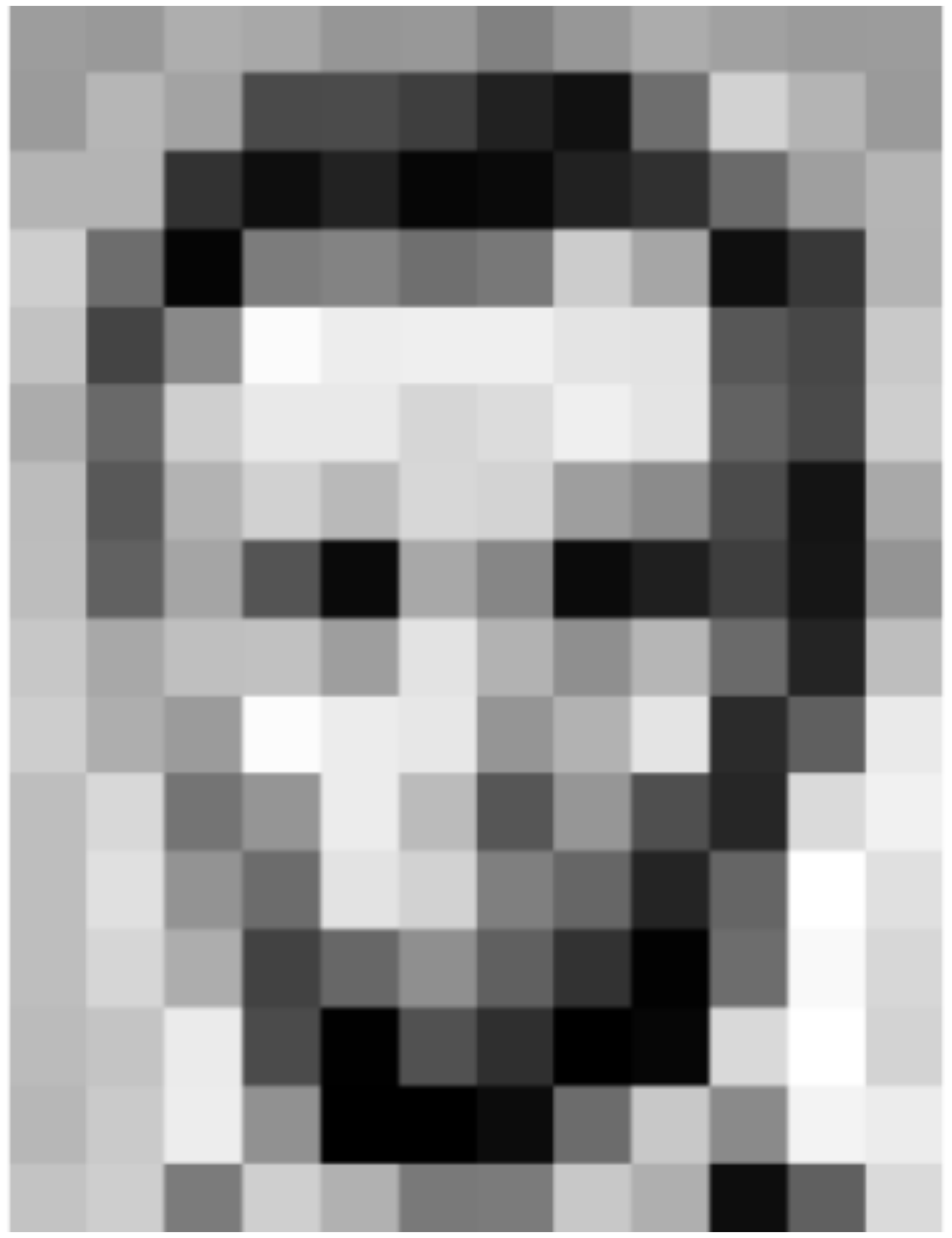
Digital Image

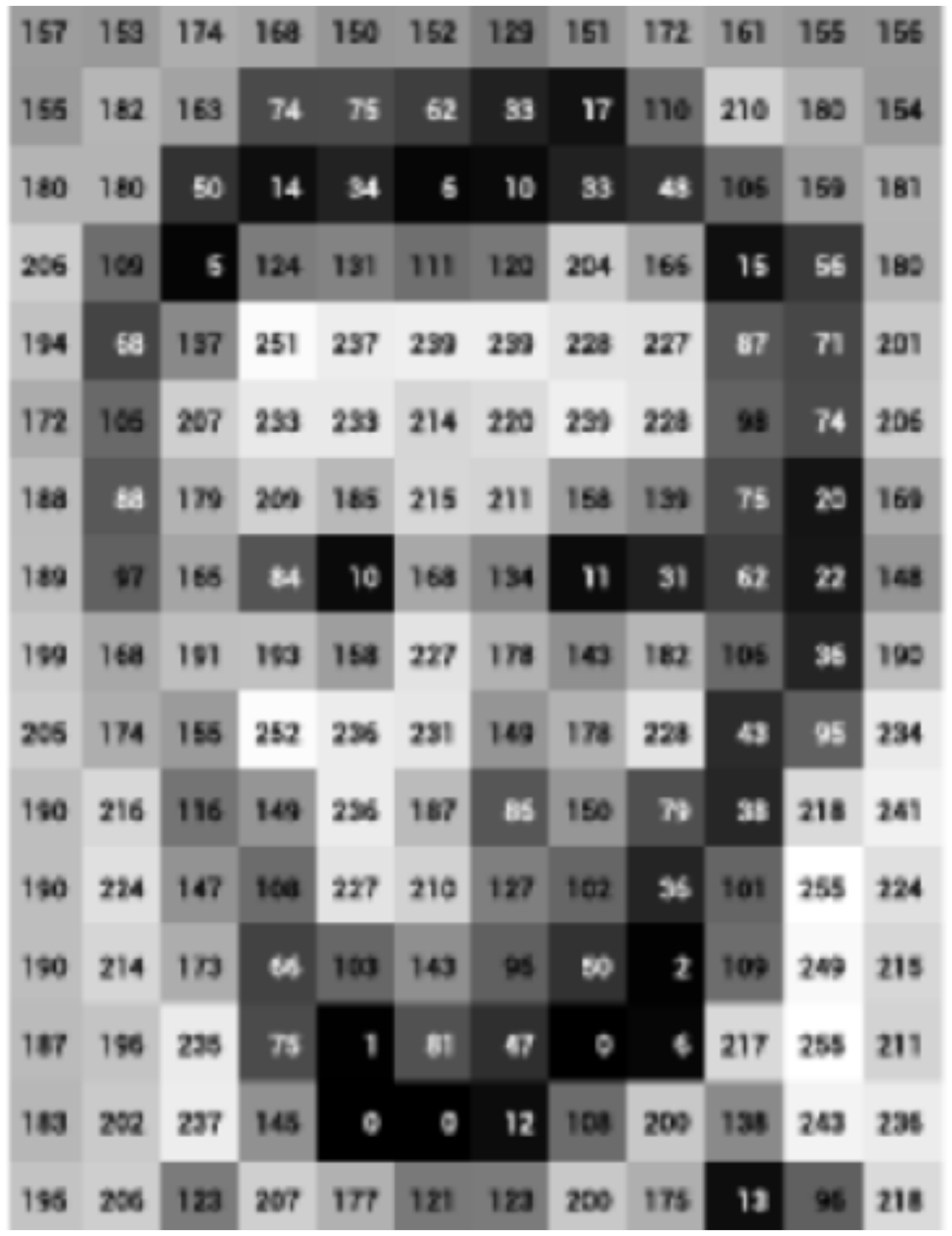




157	153	174	168	150	152	129	151	172	161	155	156
155	182	163	74	75	62	33	17	110	210	180	154
180	180	50	14	34	6	10	33	48	106	159	181
206	109	5	124	131	111	120	204	166	15	56	180
194	68	137	251	237	239	239	228	227	87	71	201
172	105	207	233	233	214	220	239	228	98	74	206
188	88	179	209	185	215	211	158	139	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

Digital Image





157	153	174	168	150	152	129	151	172	161	155	156
155	182	163	74	75	62	33	17	110	210	180	154
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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
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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
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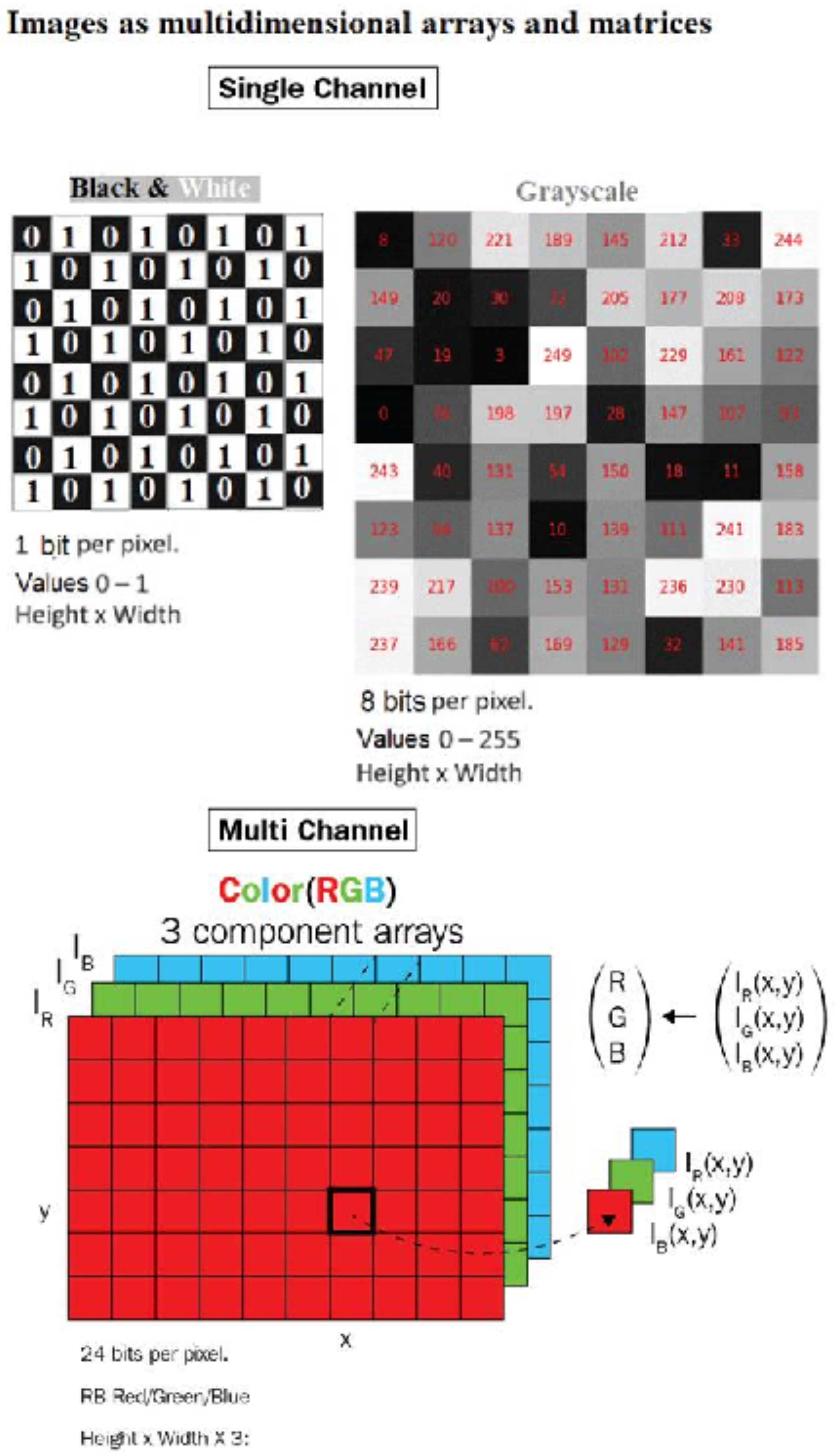


Image Processing

Input / Output	Image	Description
Image		
Description		

Image Processing

Input \ Output	Image	Description
Image	Digital image processing	
Description		

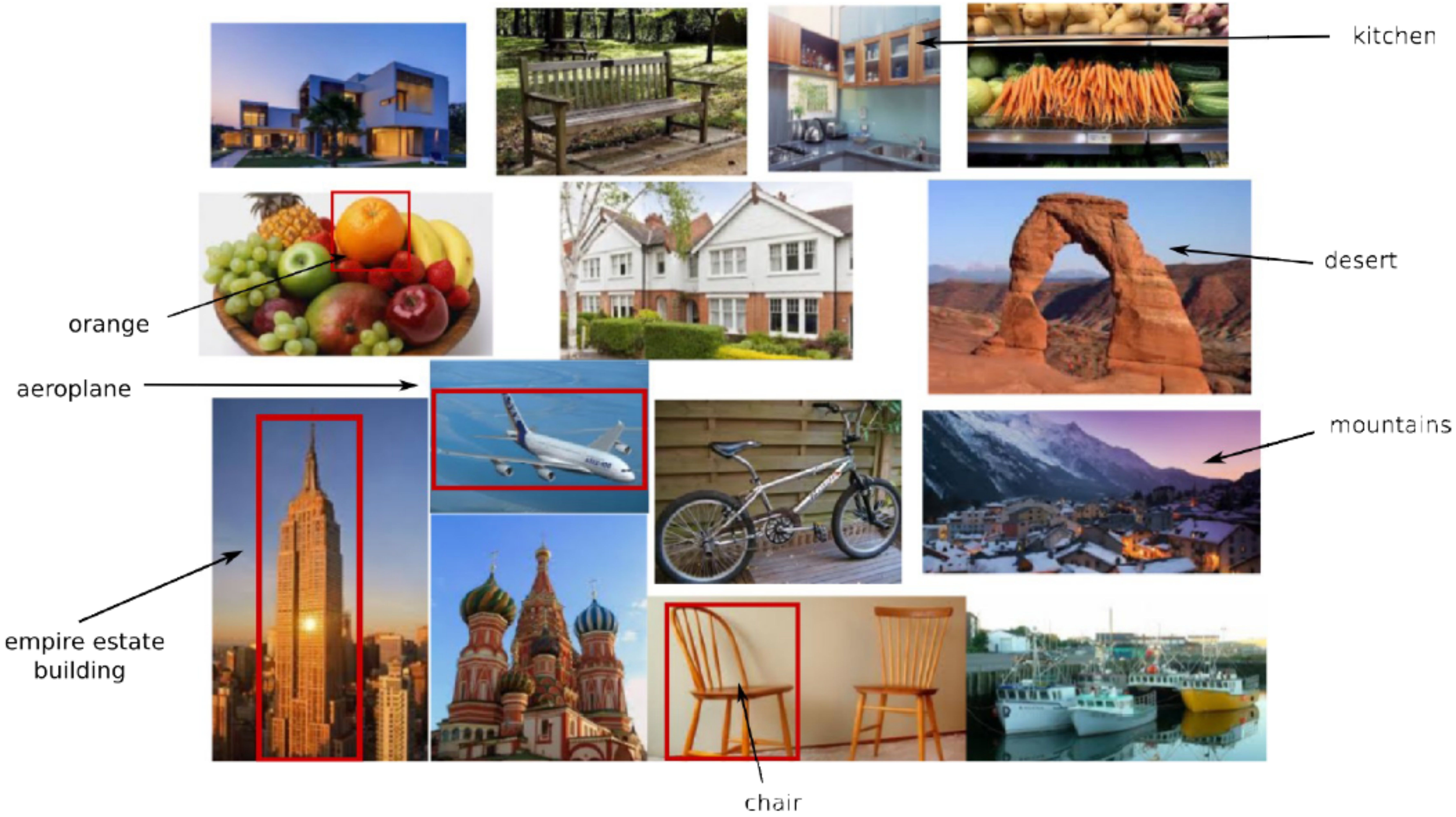
Image Processing

Input \ Output	Image	Description
Image	Digital image processing	Computer vision
Description	Computer graphics	

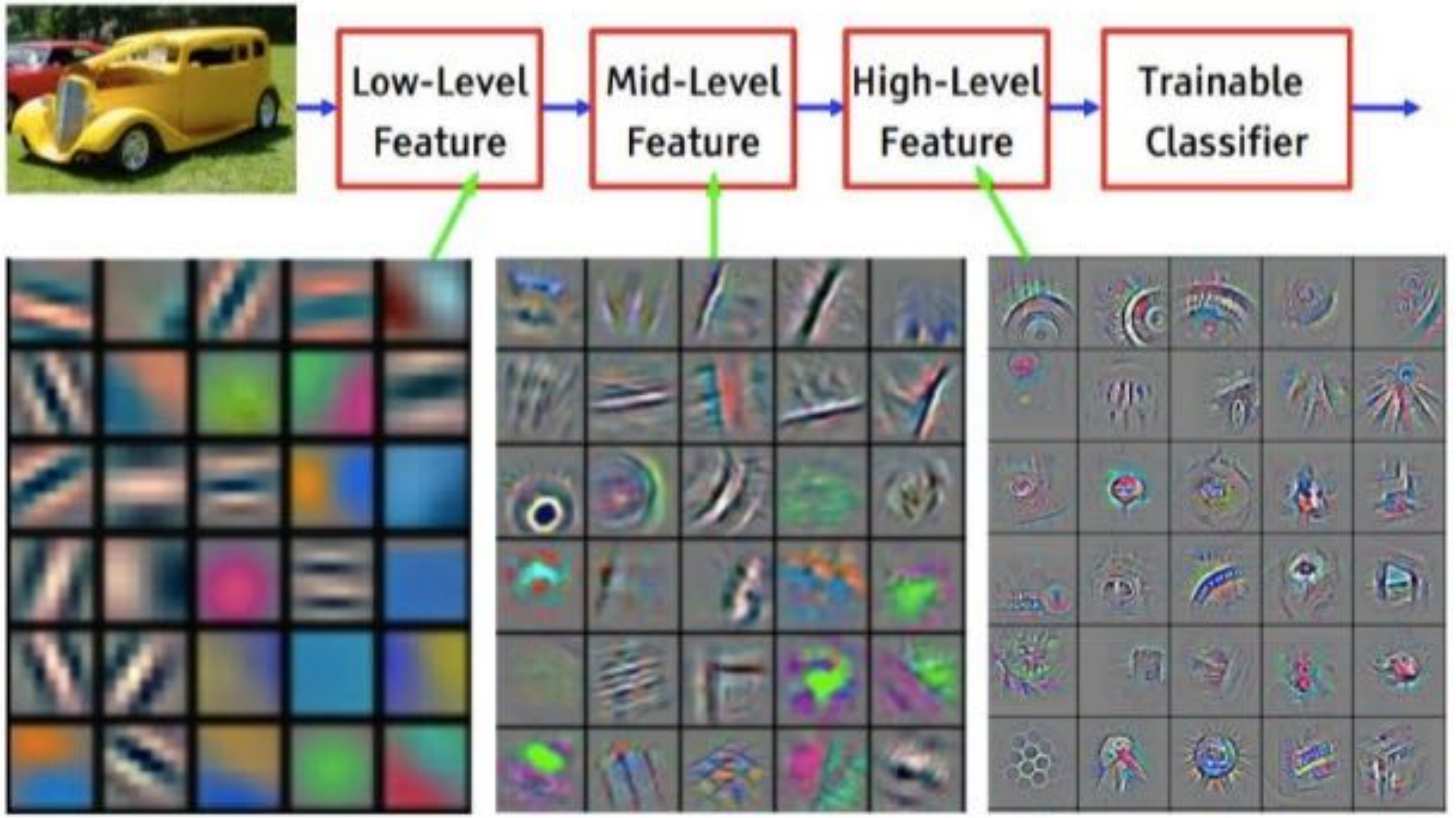
Image Processing

Input \ Output	Image	Description
Image	Digital image processing	Computer vision
Description	Computer graphics	Artificial intelligence

Motivation: Model and Understand the World



Traditional vs Deep Learning Approaches

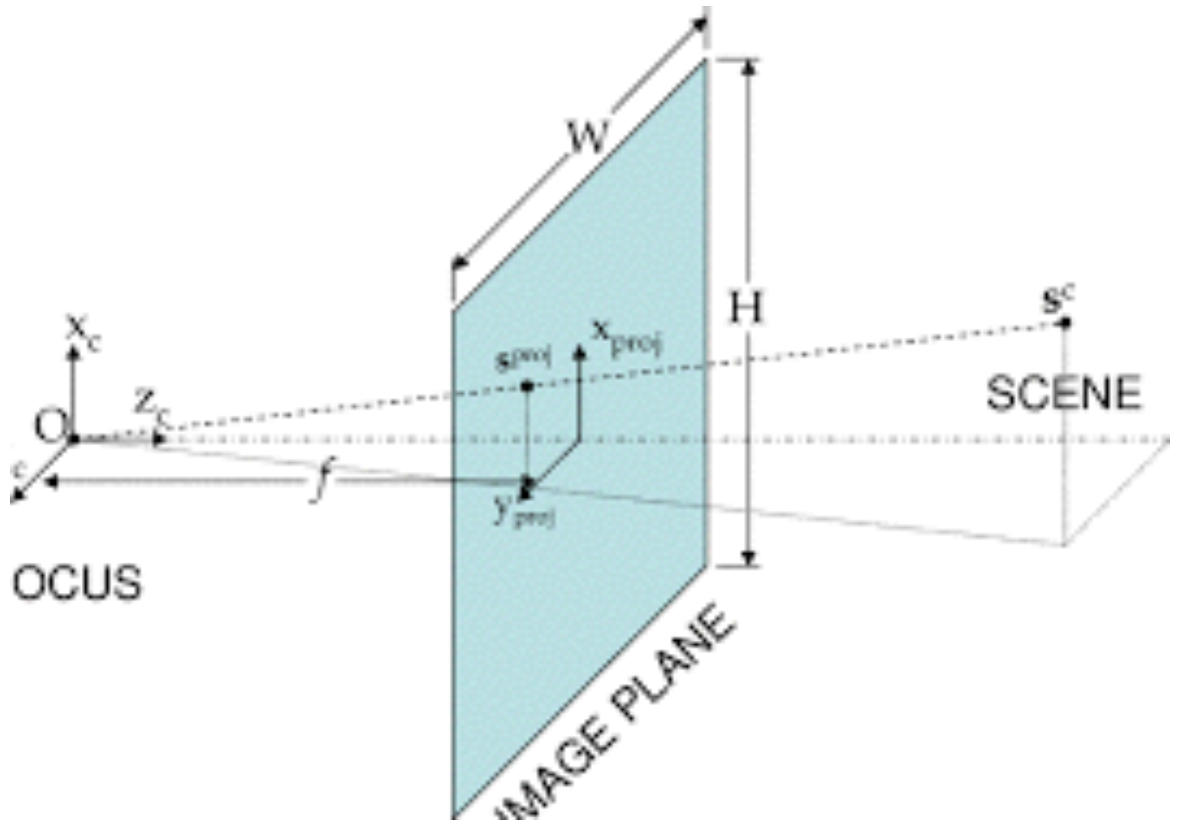


Feature visualization of convolutional net trained on ImageNet from [Zeiler & Fergus 2013]

Image Formation and Settings

Image Formation and Settings

Image formation



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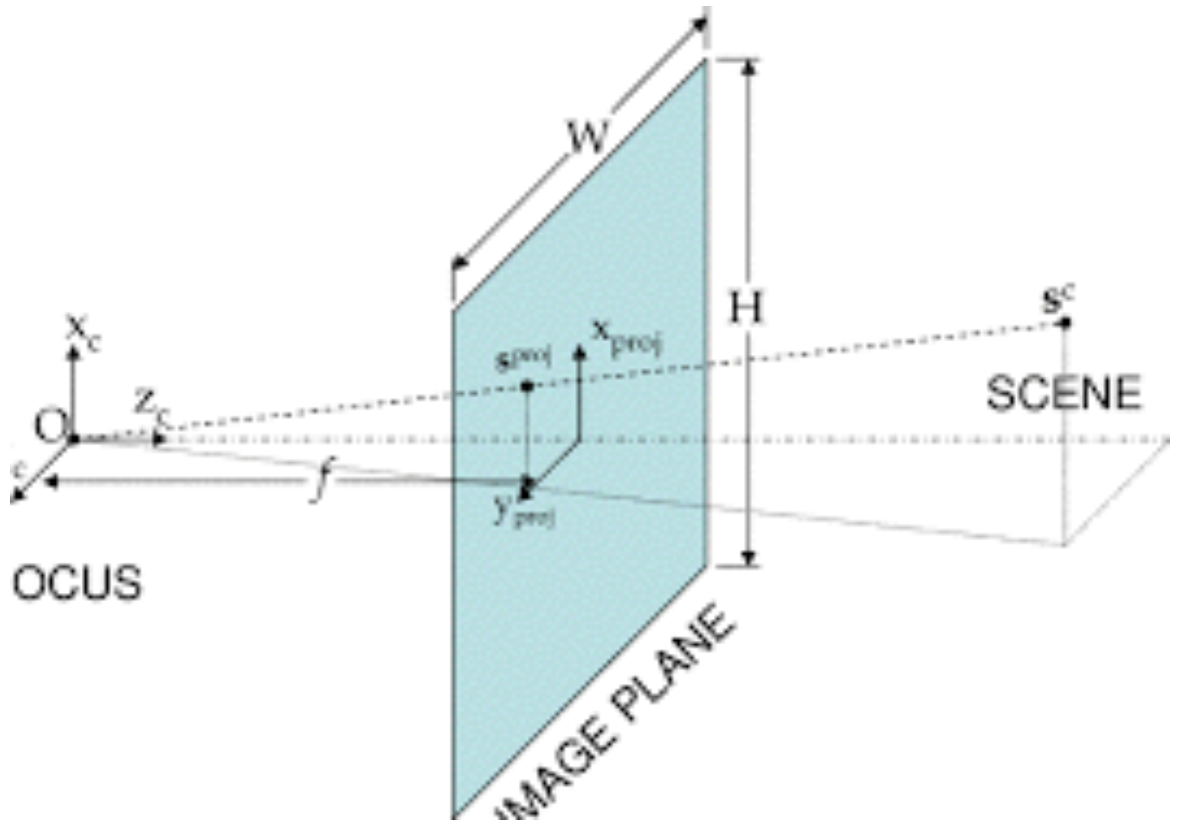


Sensors

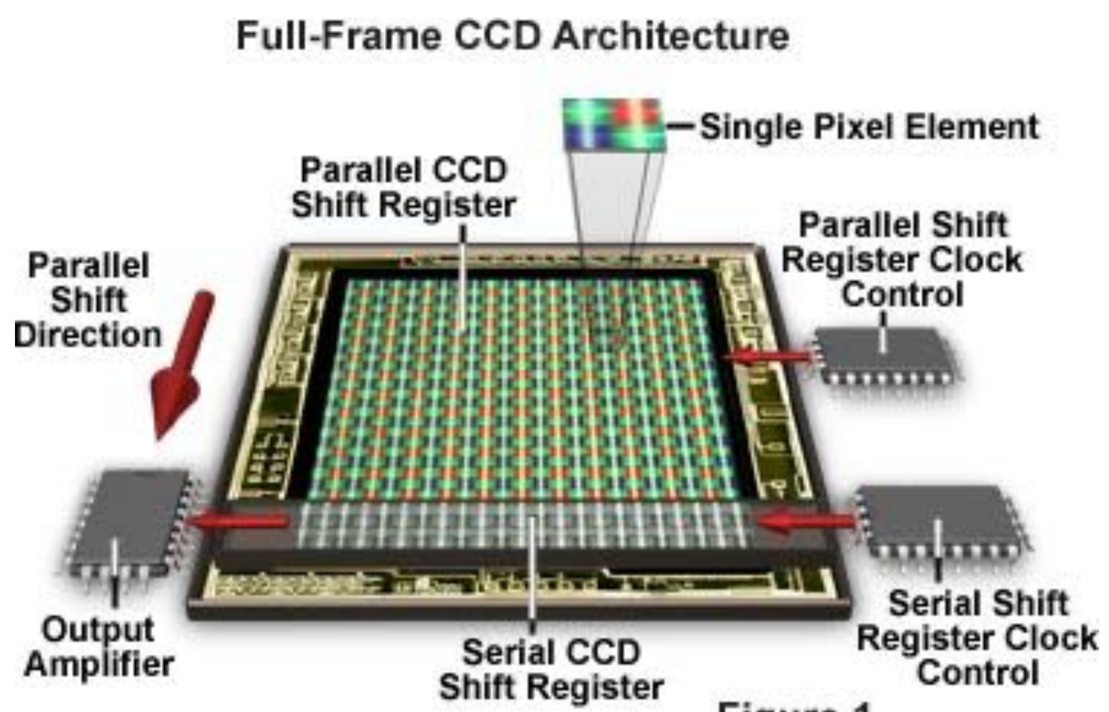
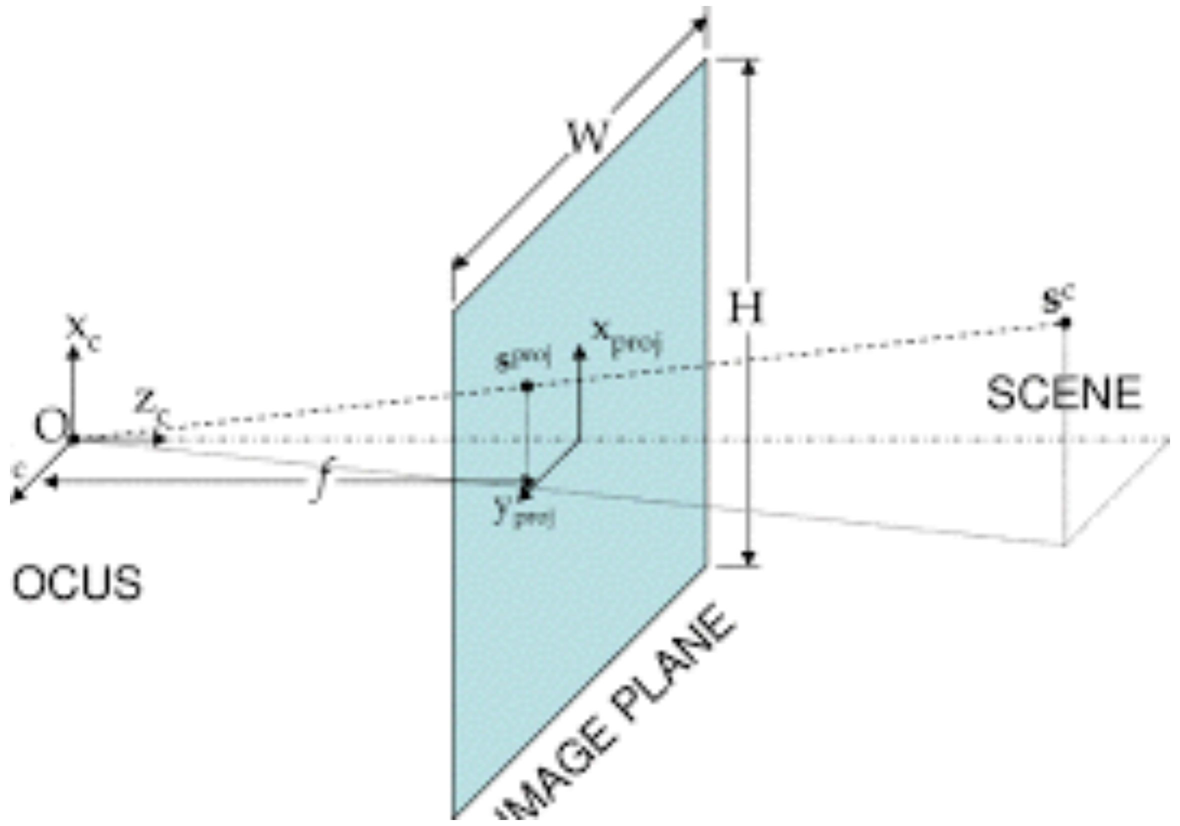


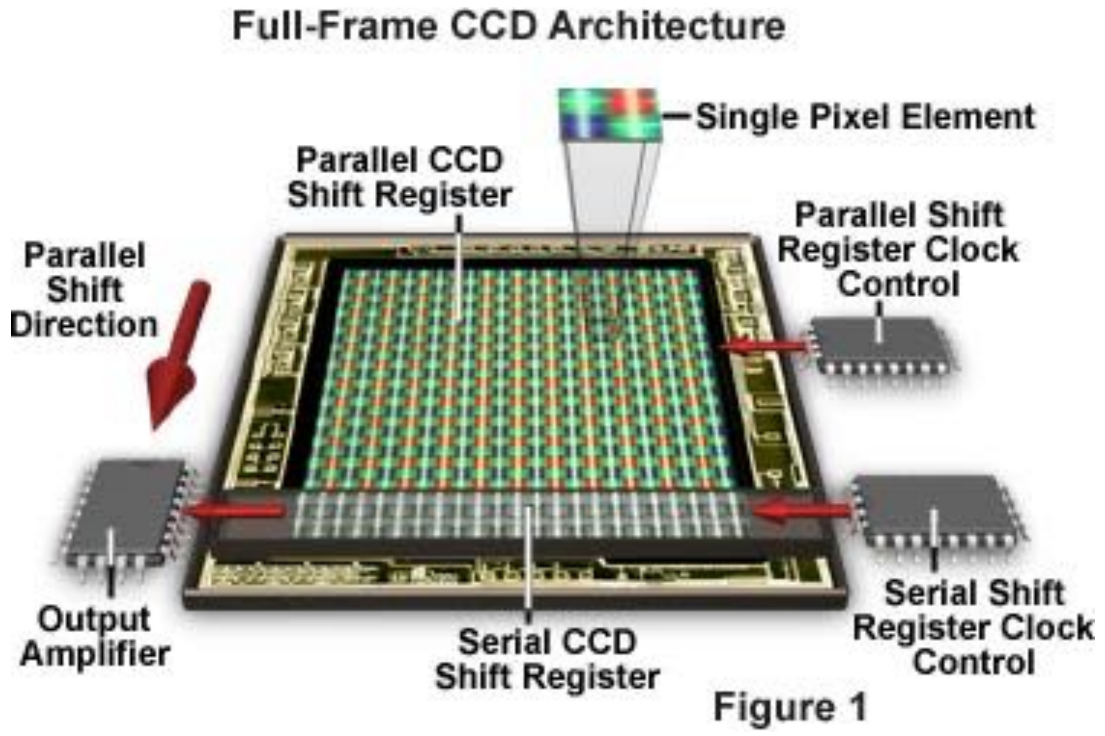
Figure 1

Image Formation and Settings

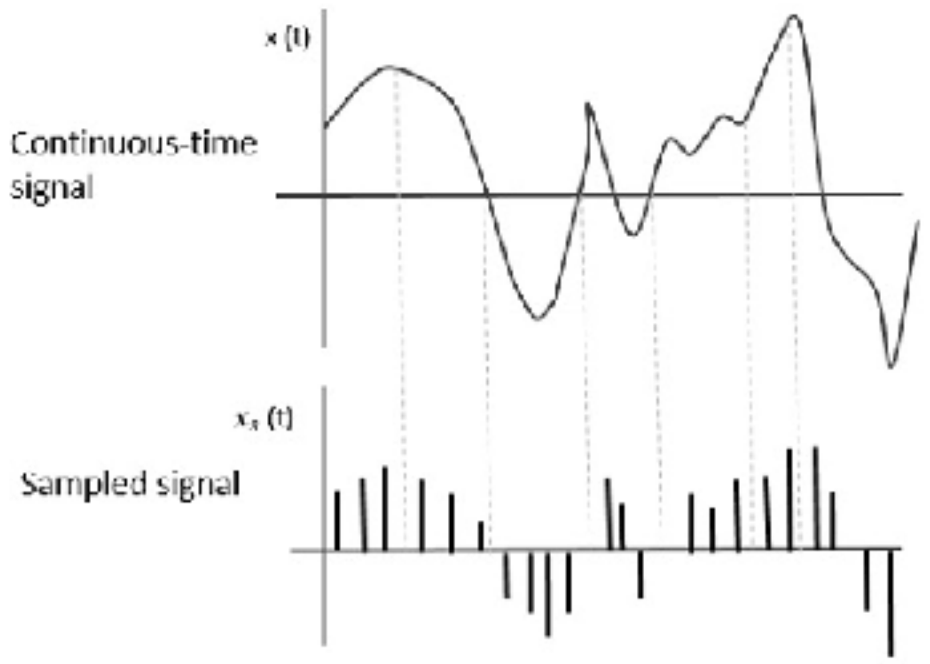
Image formation



Sensors



Sampling



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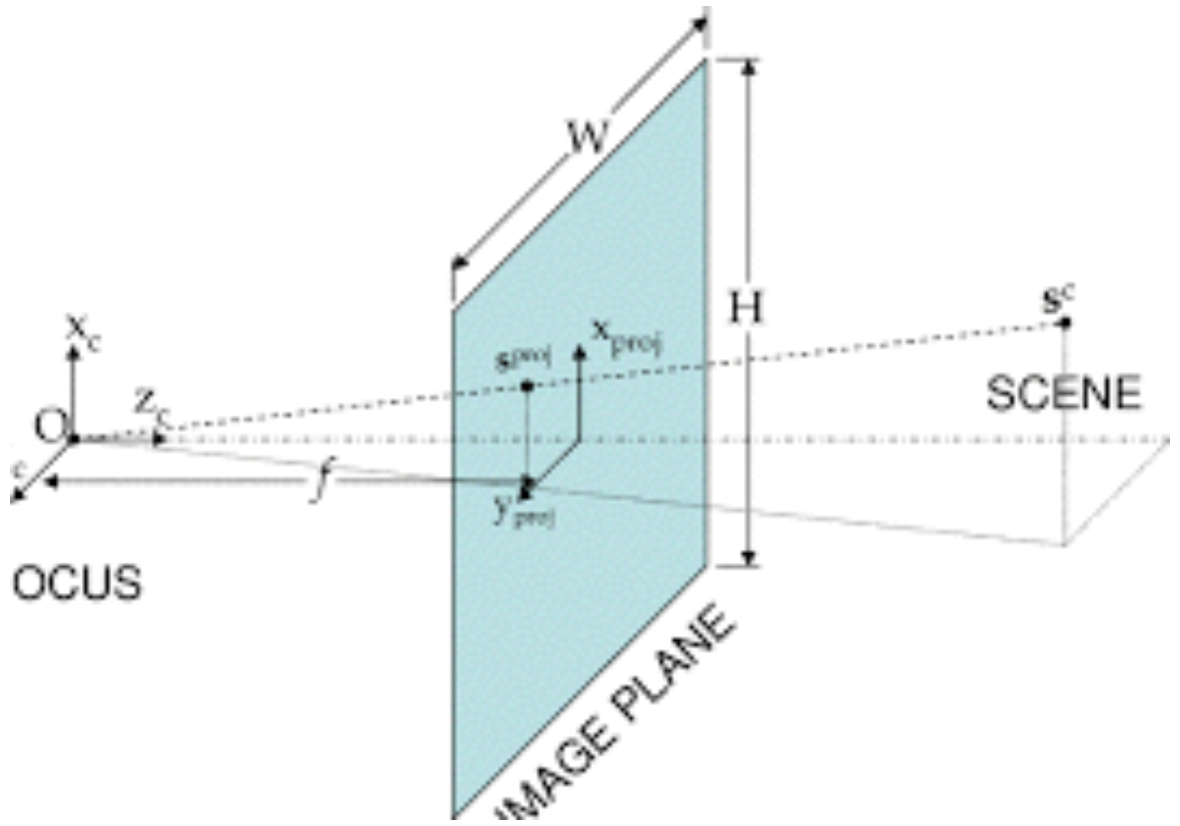
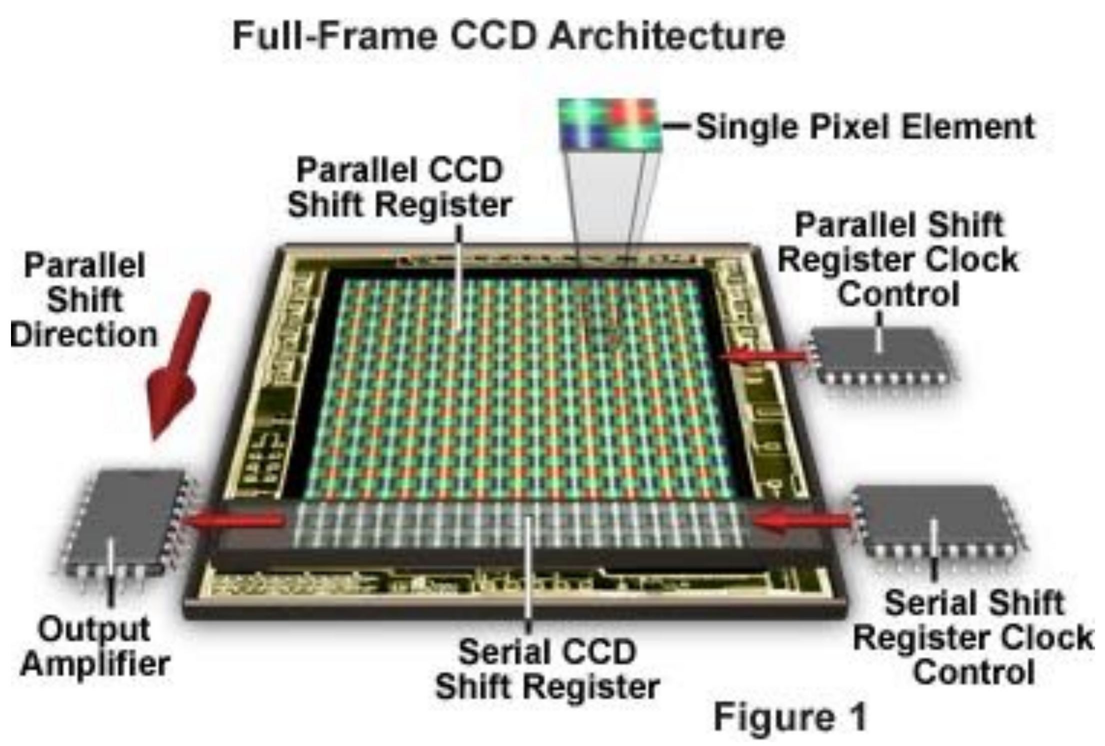
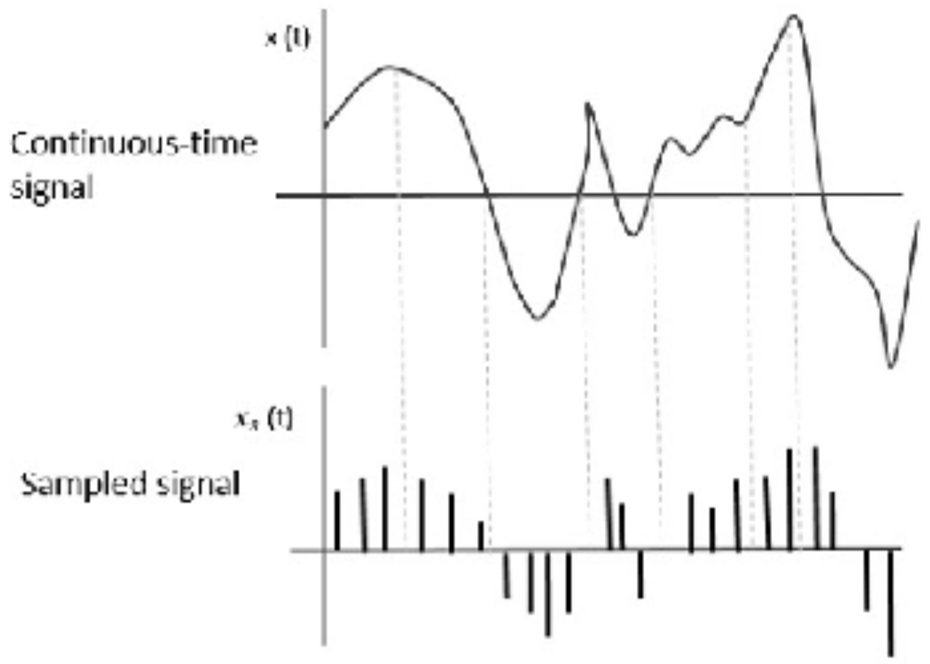


Sensors



Sampling



Aliasing

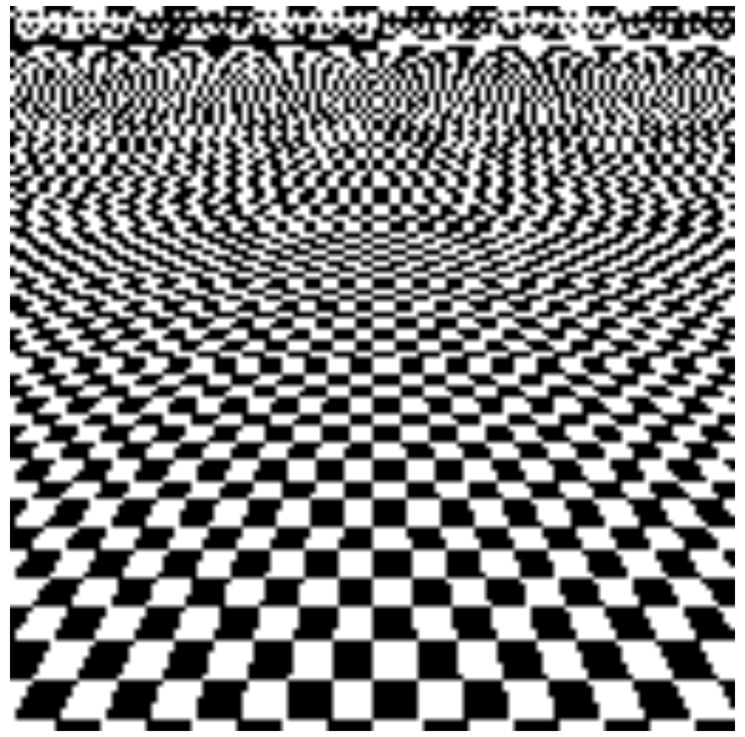
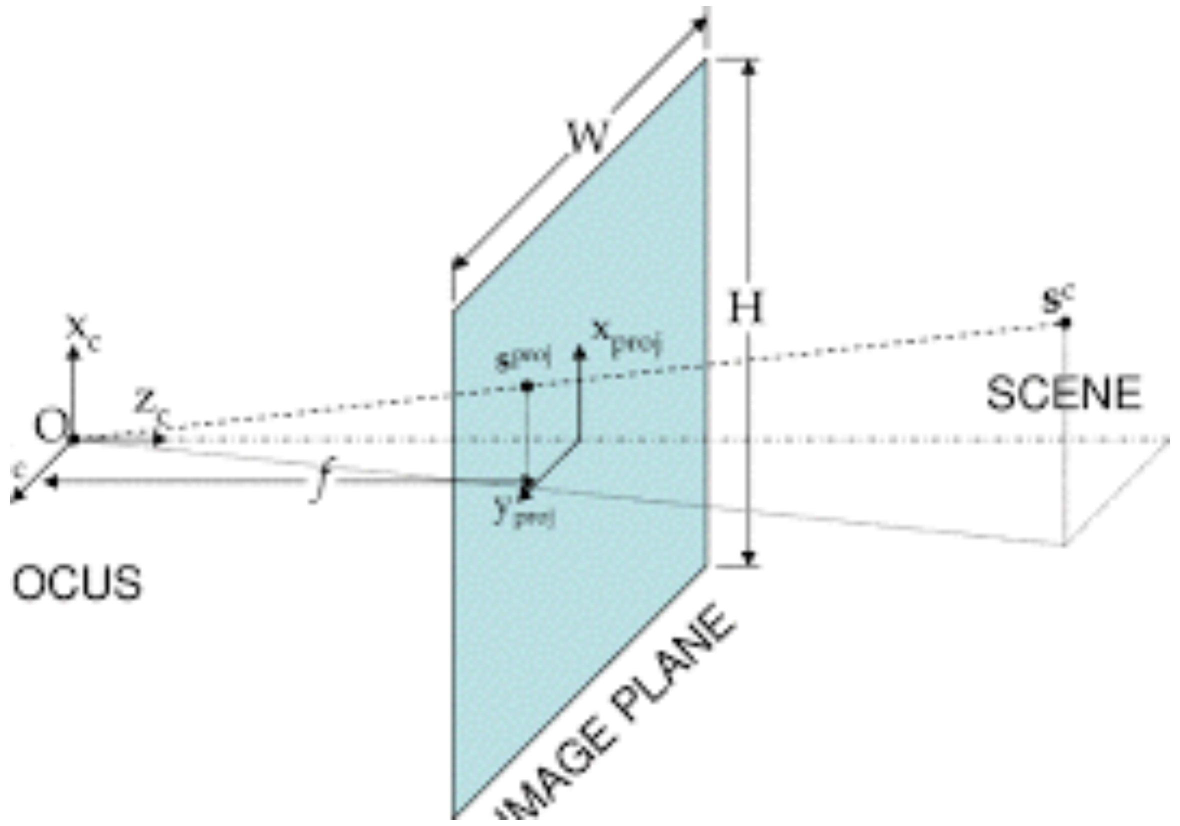
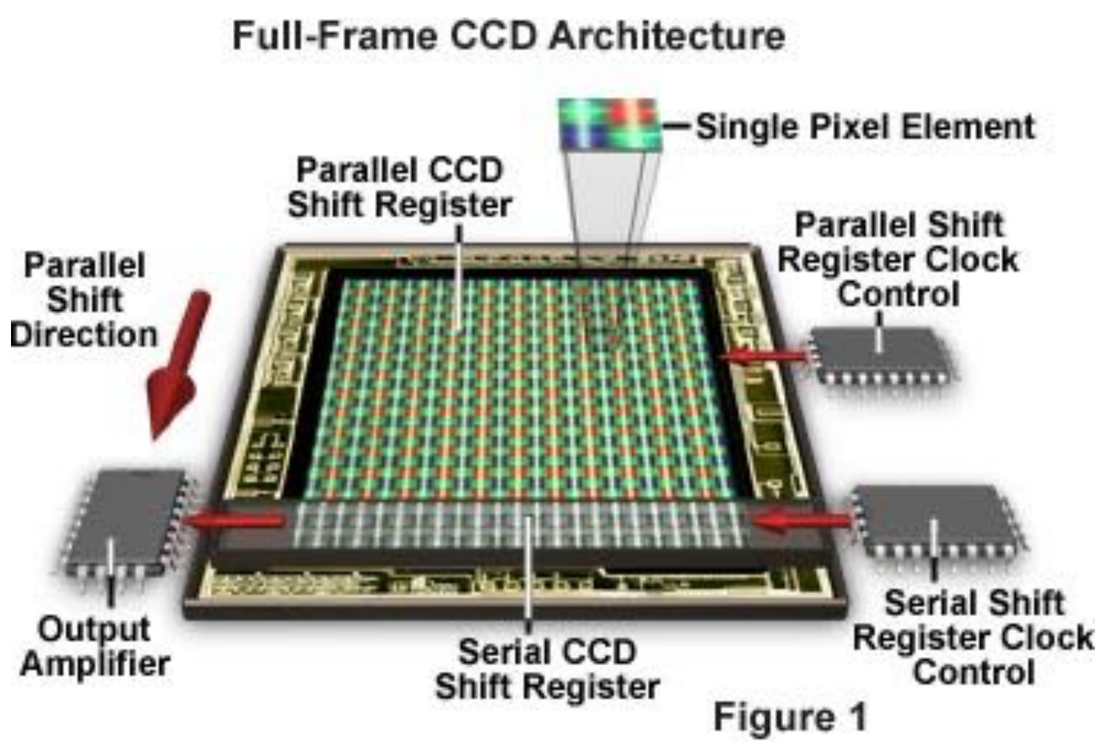


Image Formation and Settings

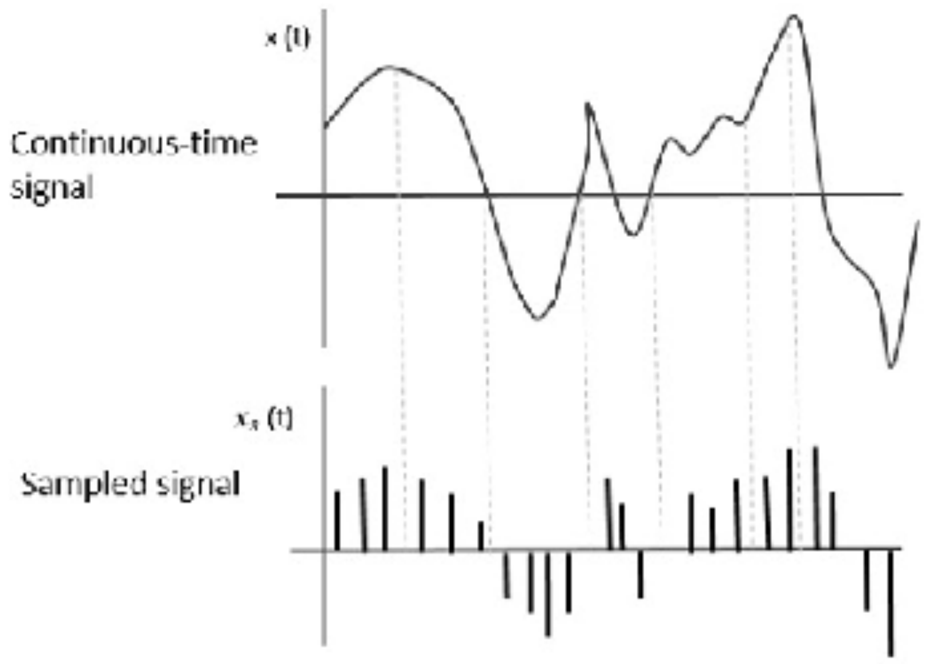
Image formation



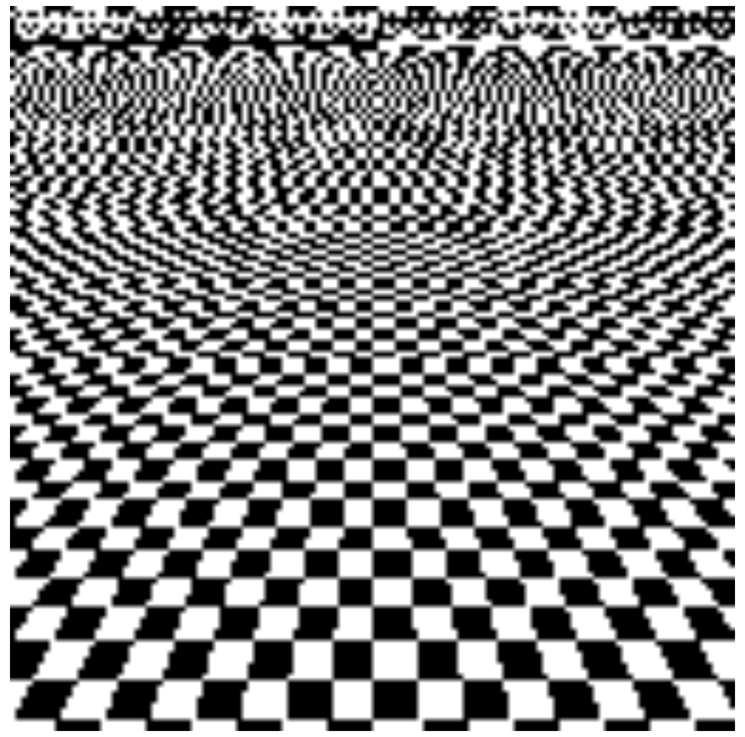
Sensors



Sampling



Aliasing



Quantization

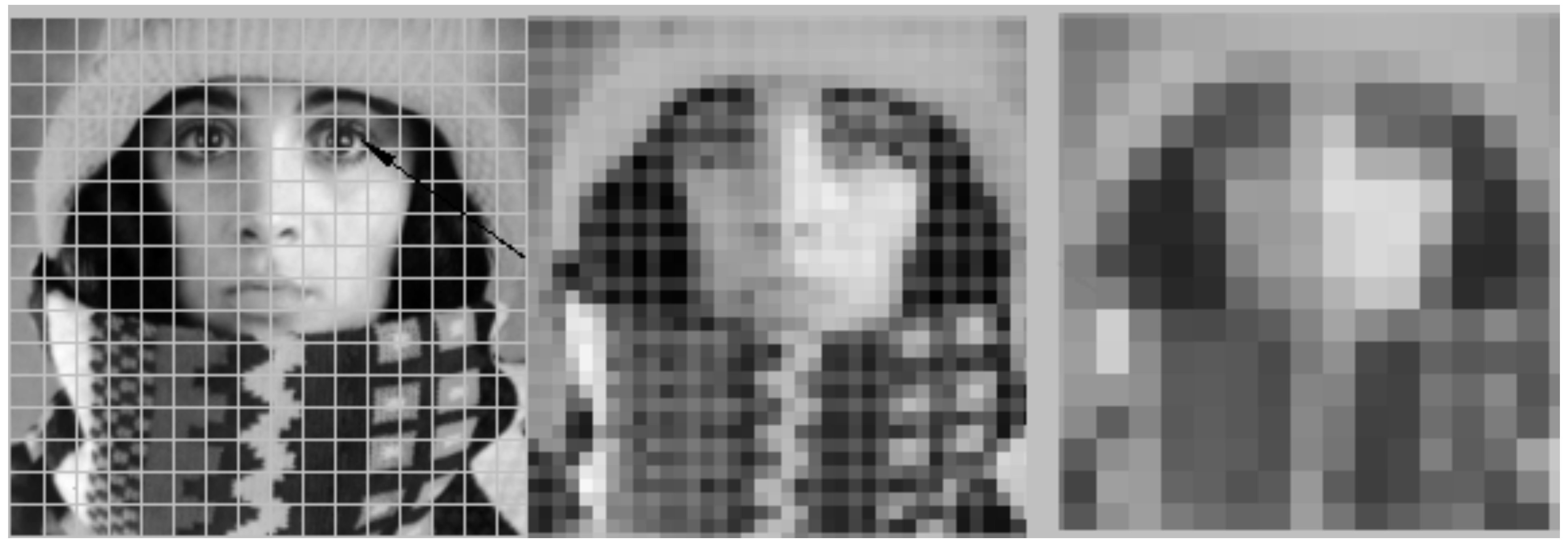
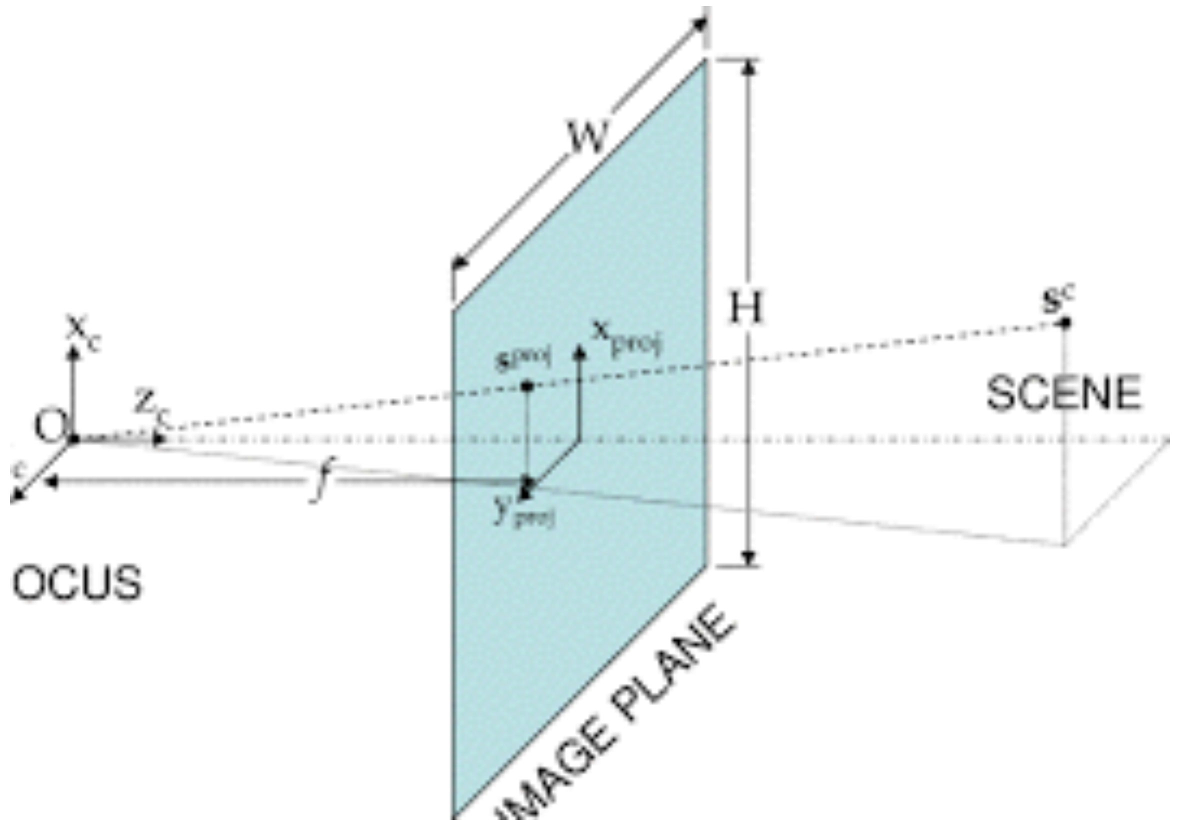
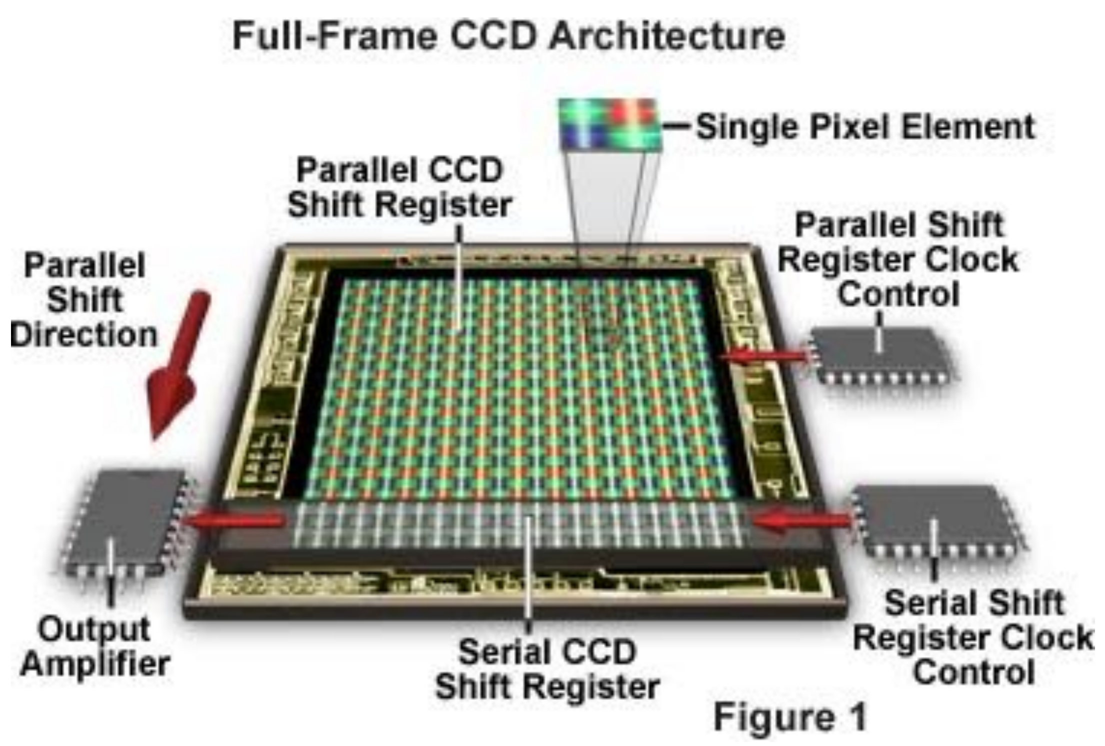


Image Formation and Settings

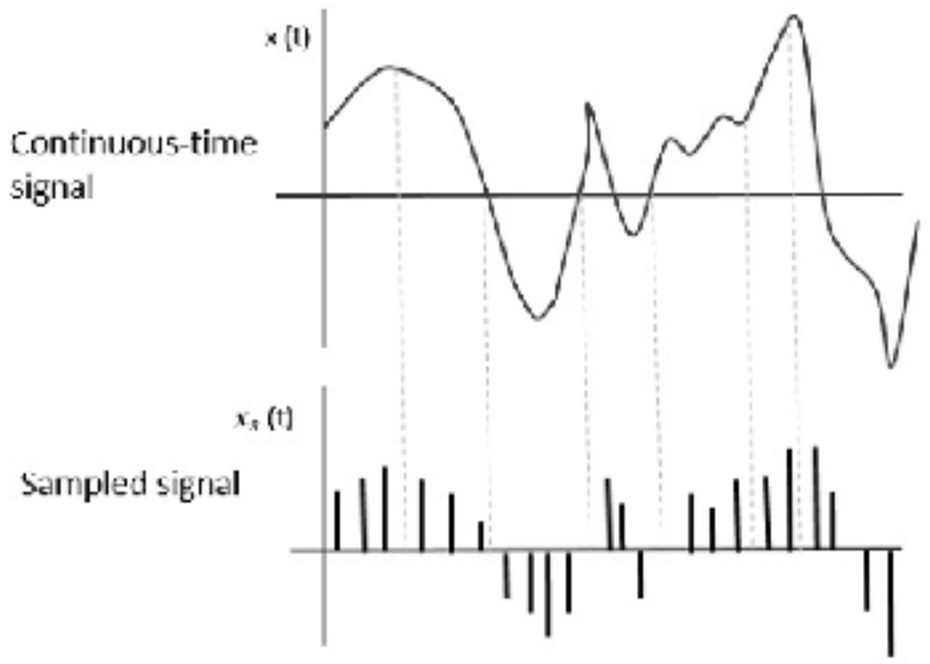
Image formation



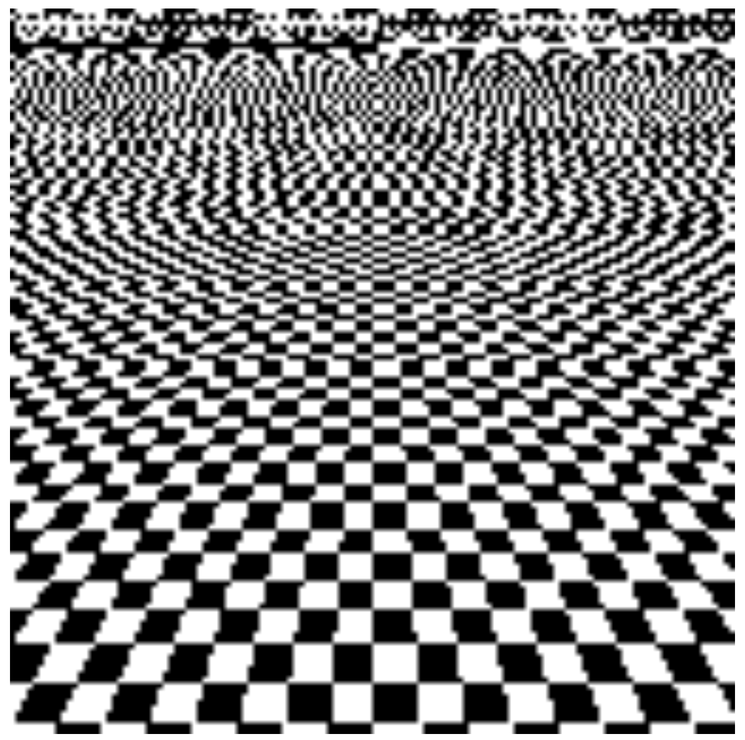
Sensors



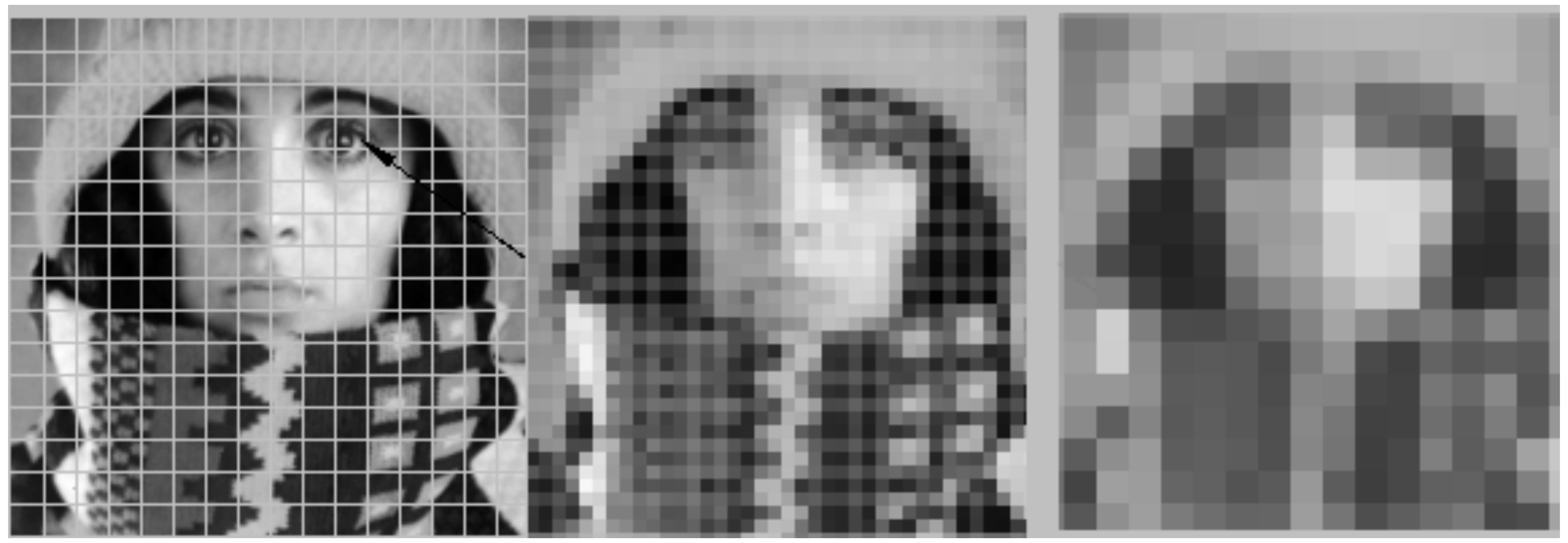
Sampling



Aliasing



Quantization



Resolution

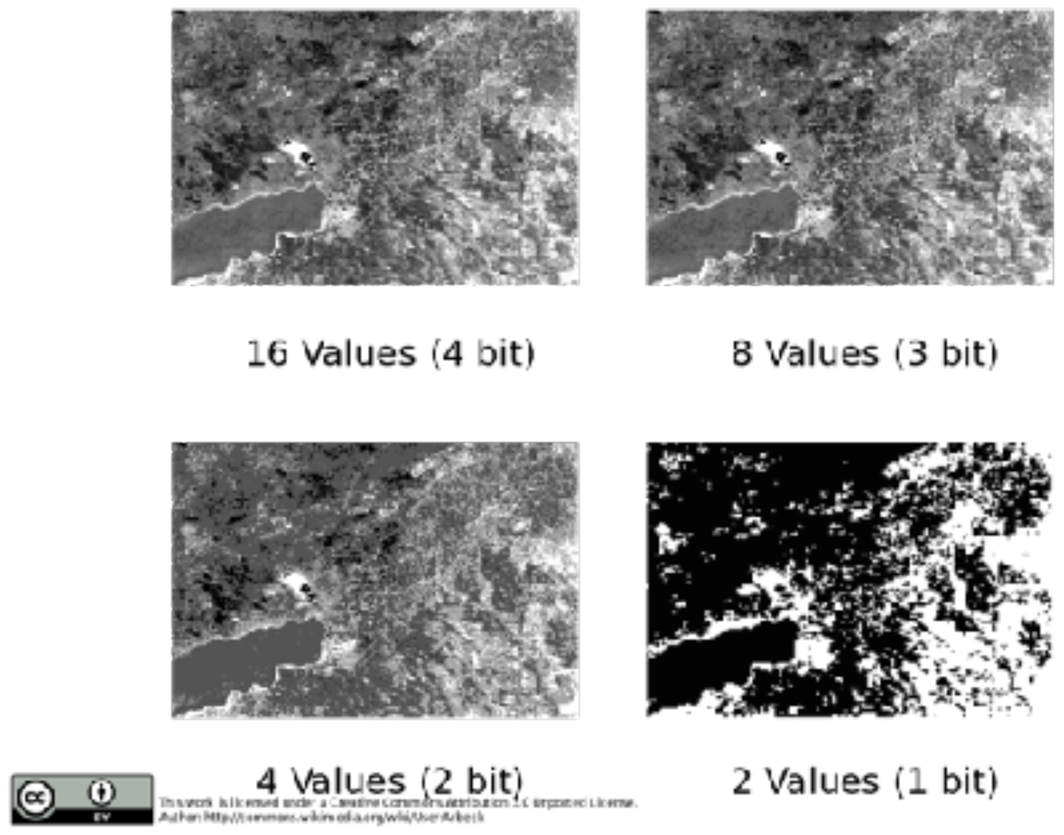
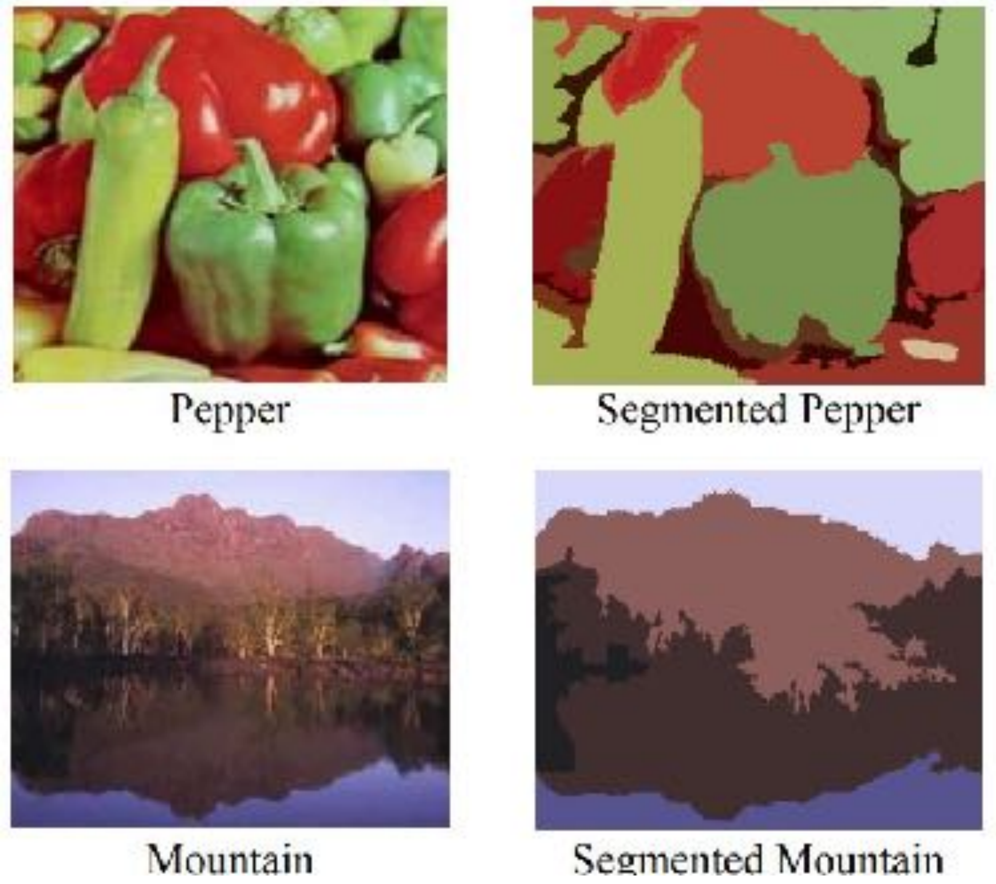


Image Segmentation

Image Segmentation

Segmentation



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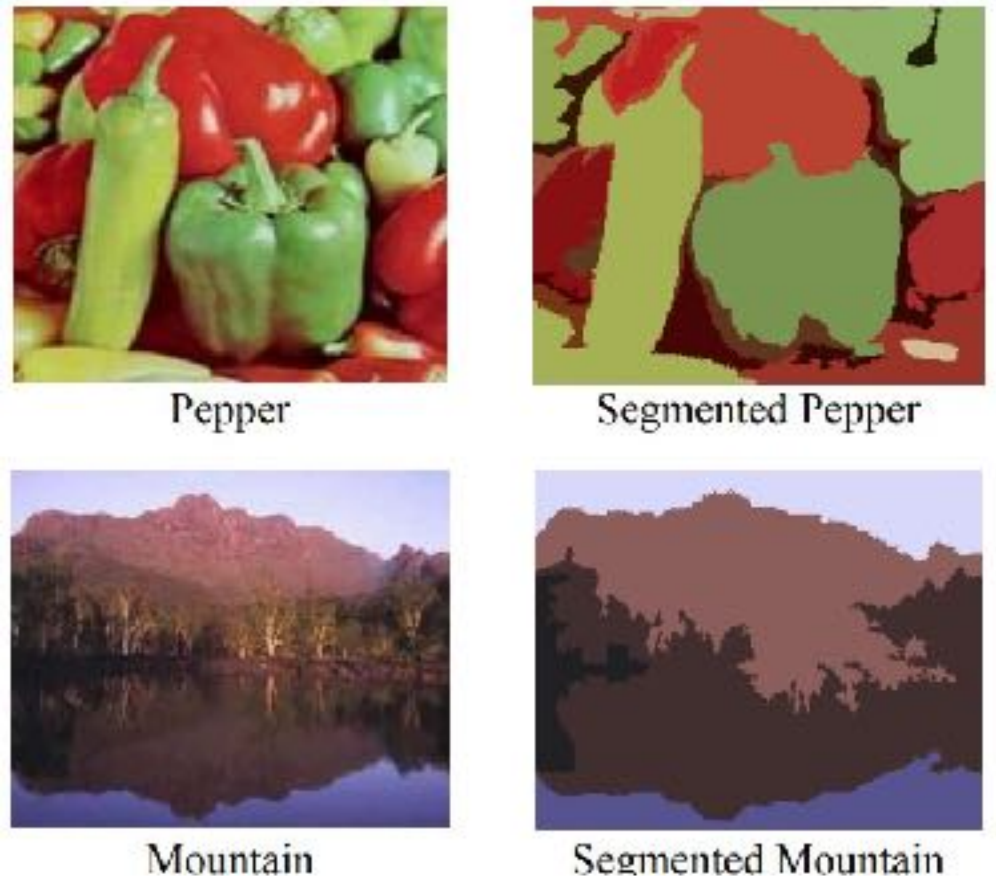
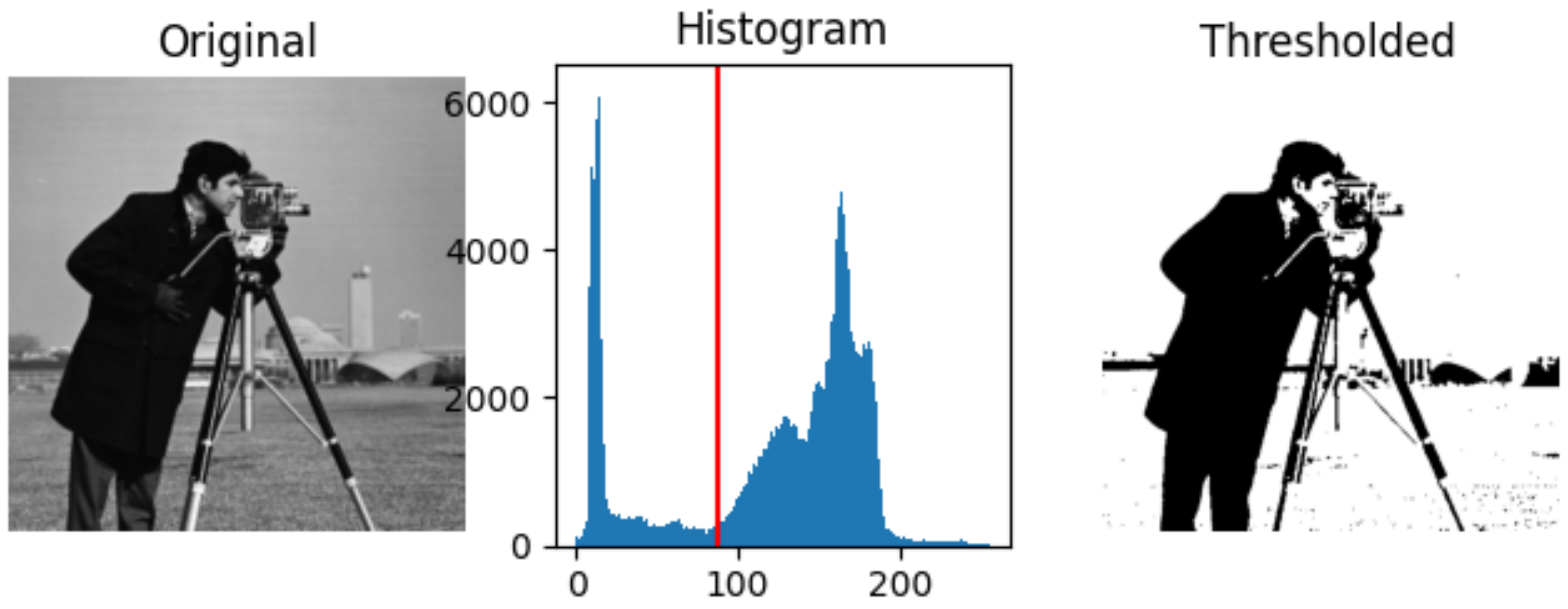


Thresholding



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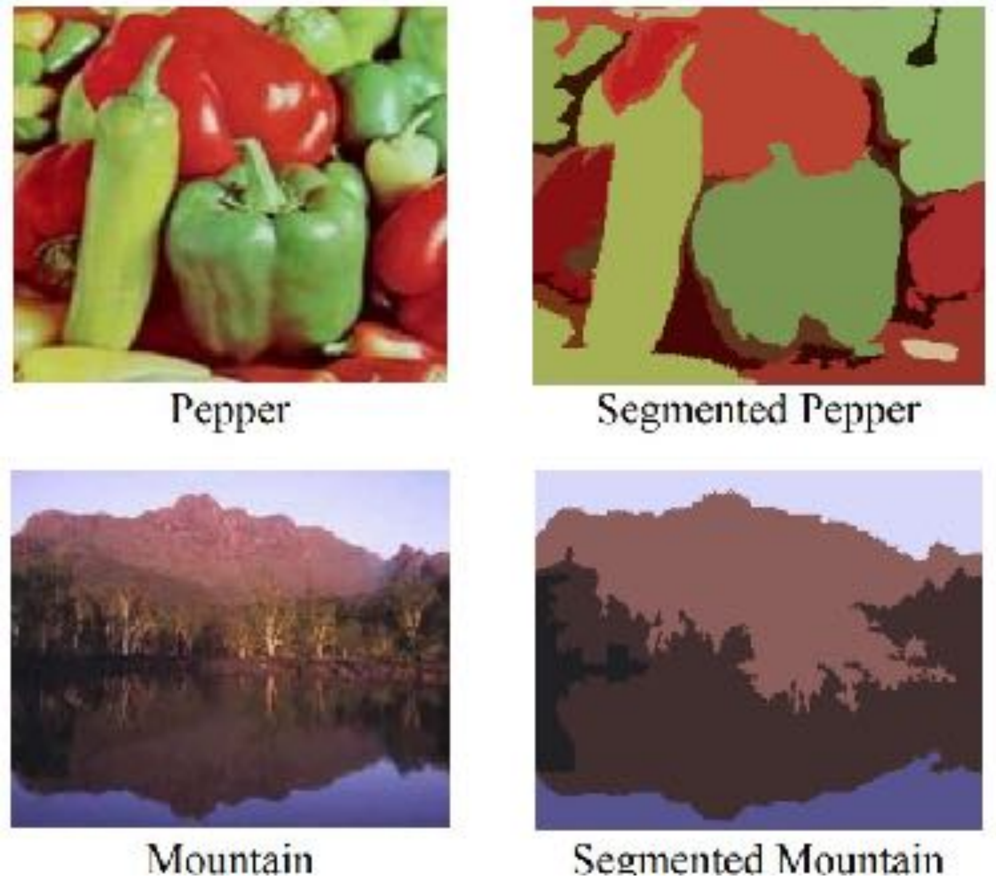
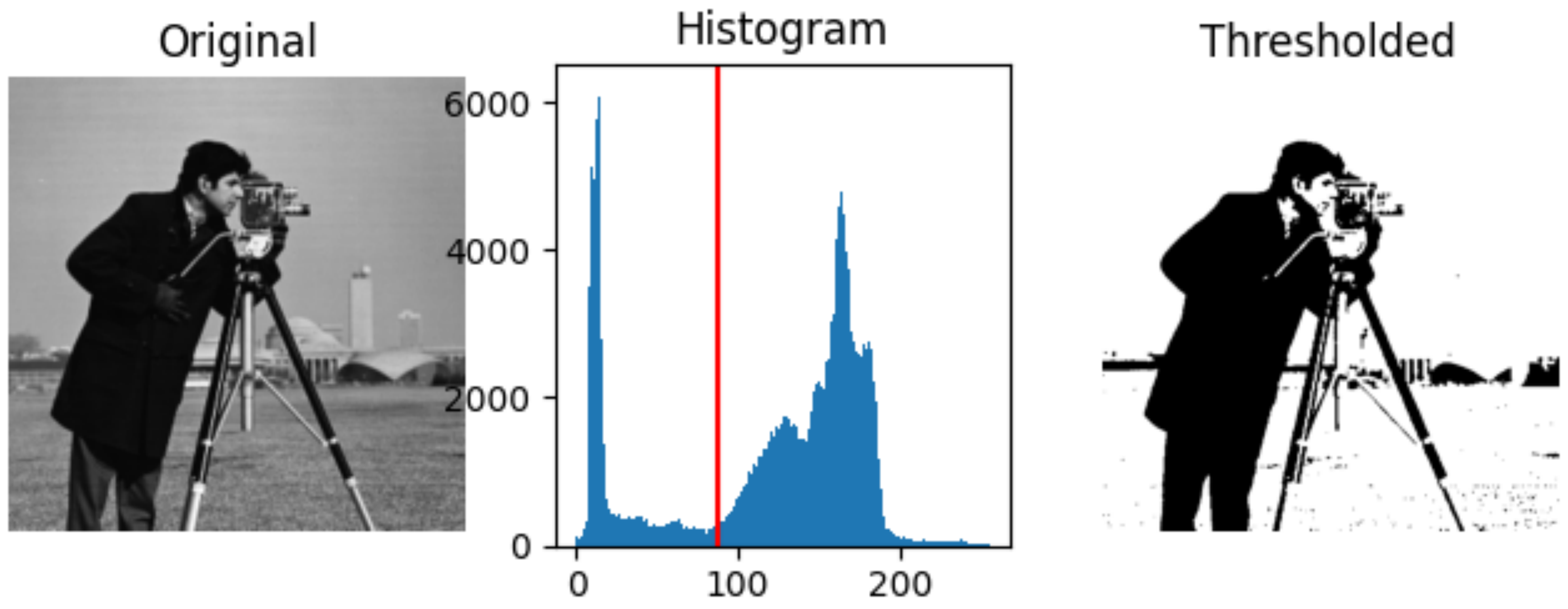


Thresholding



Connected components

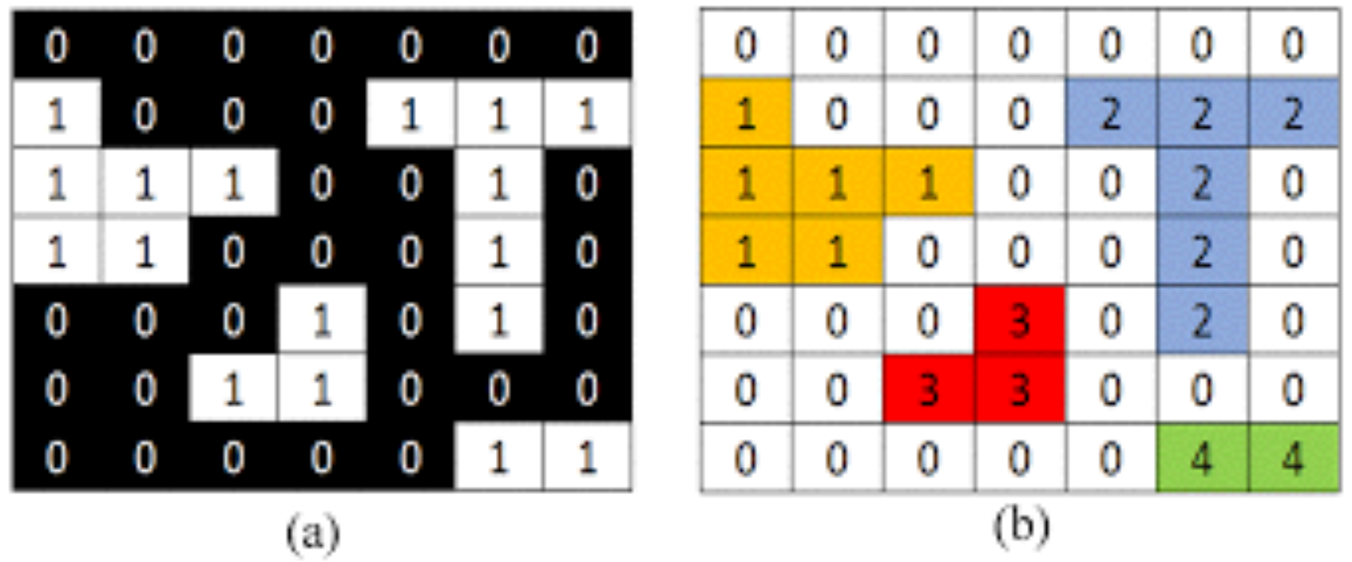


Image Segmentation

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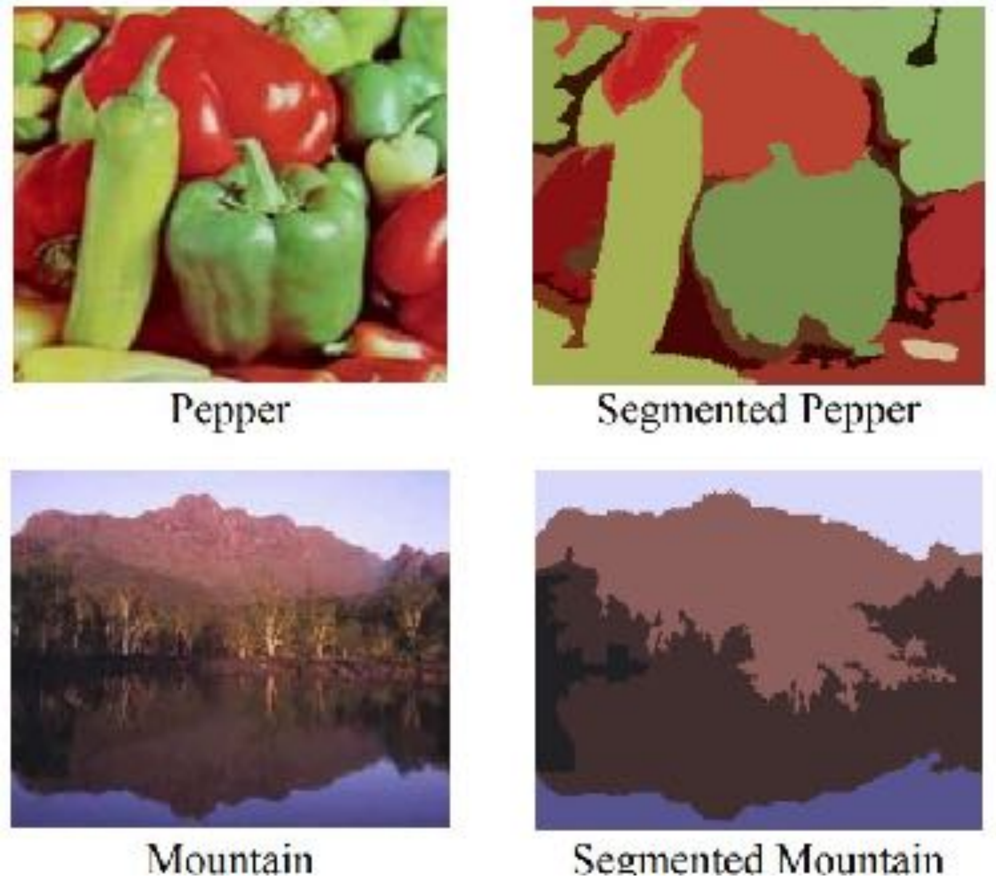

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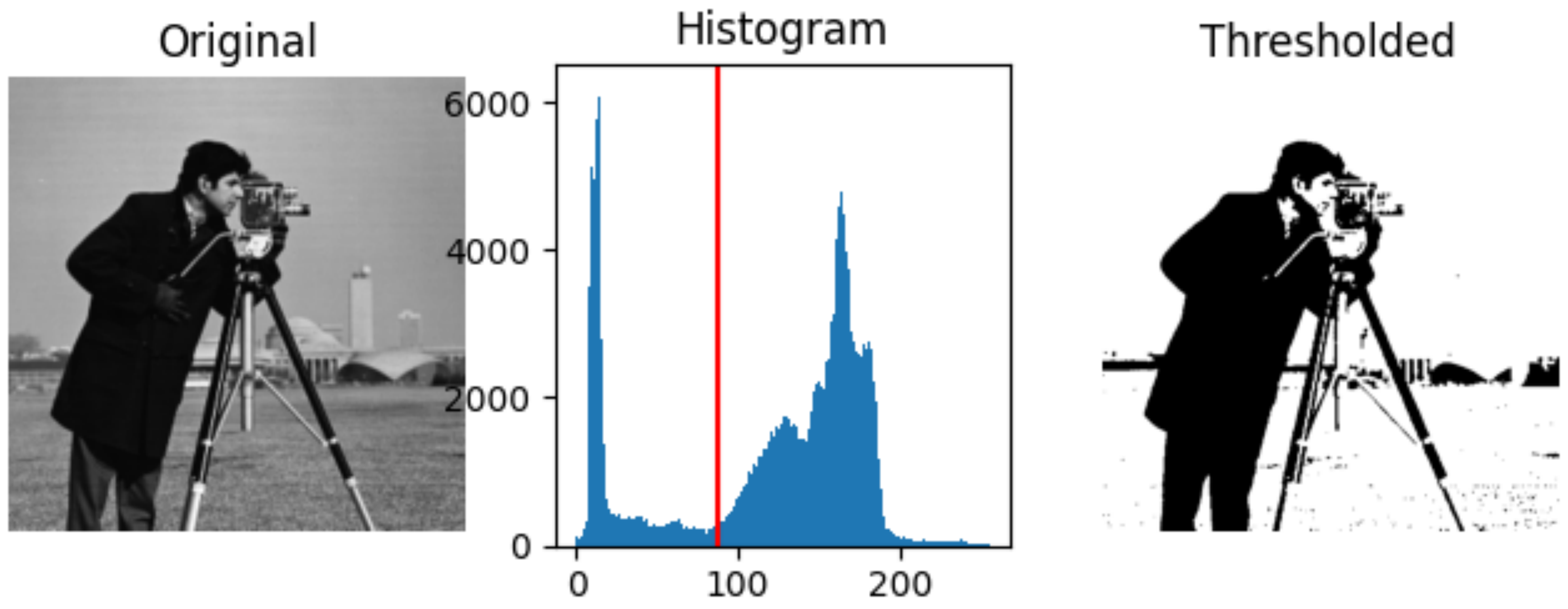

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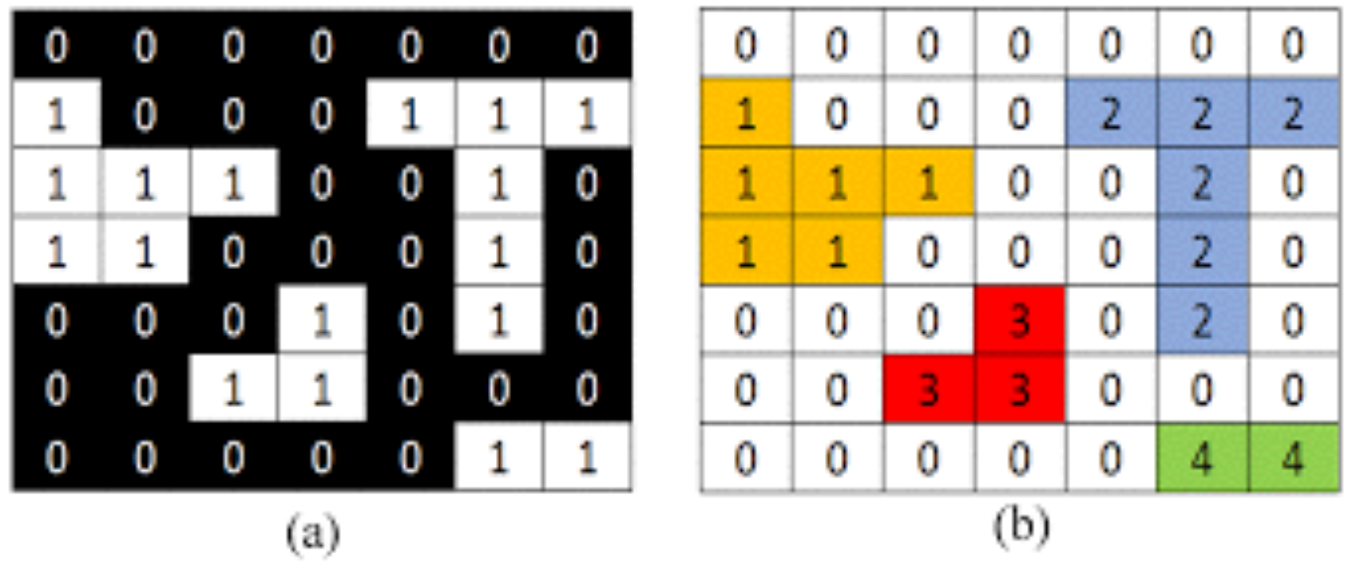


Clustering

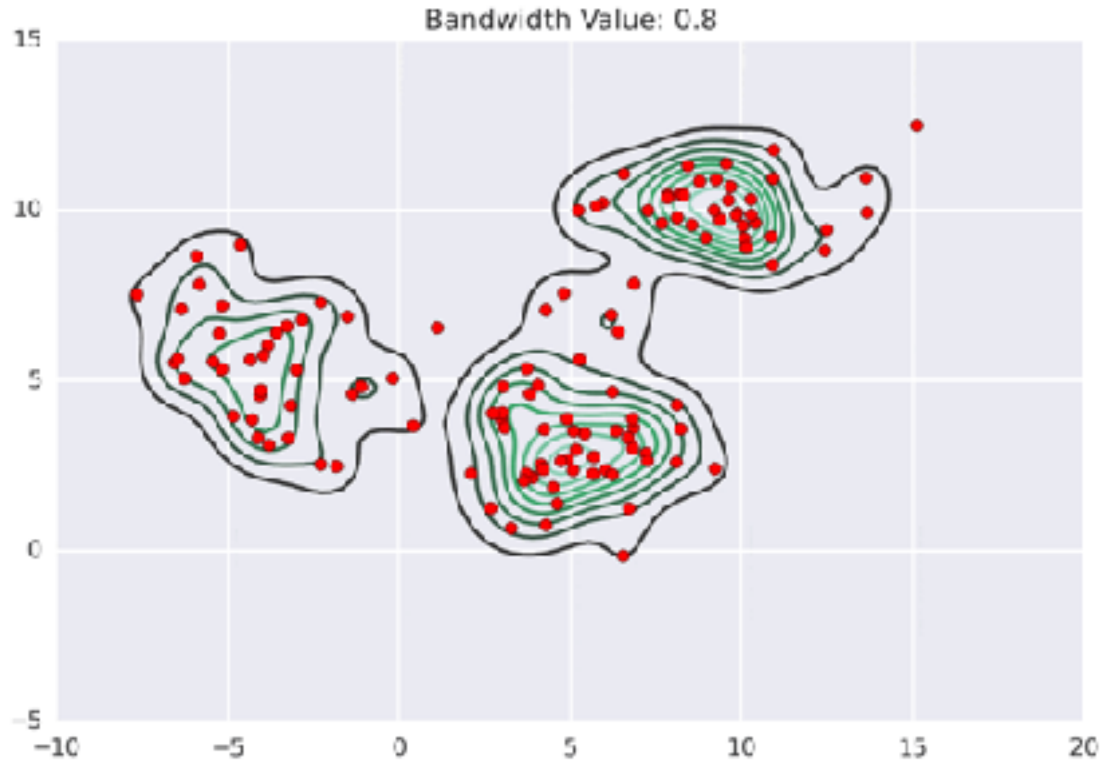
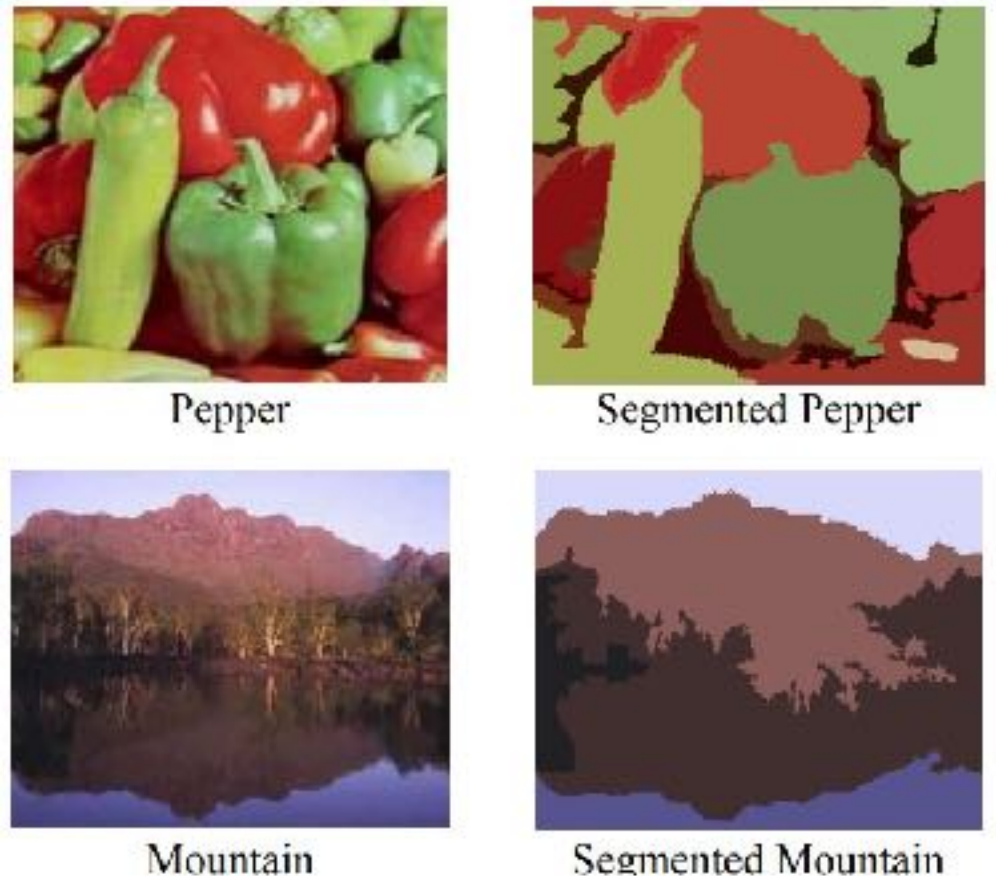
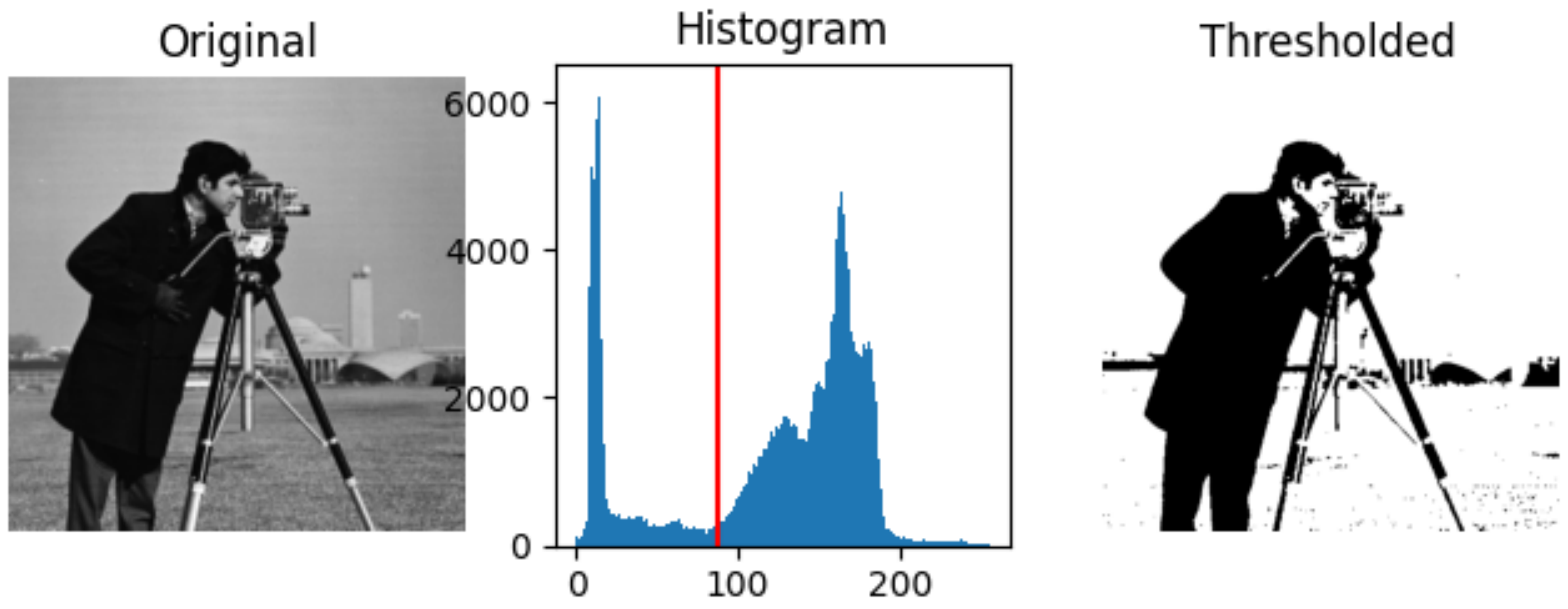


Image Segmentation

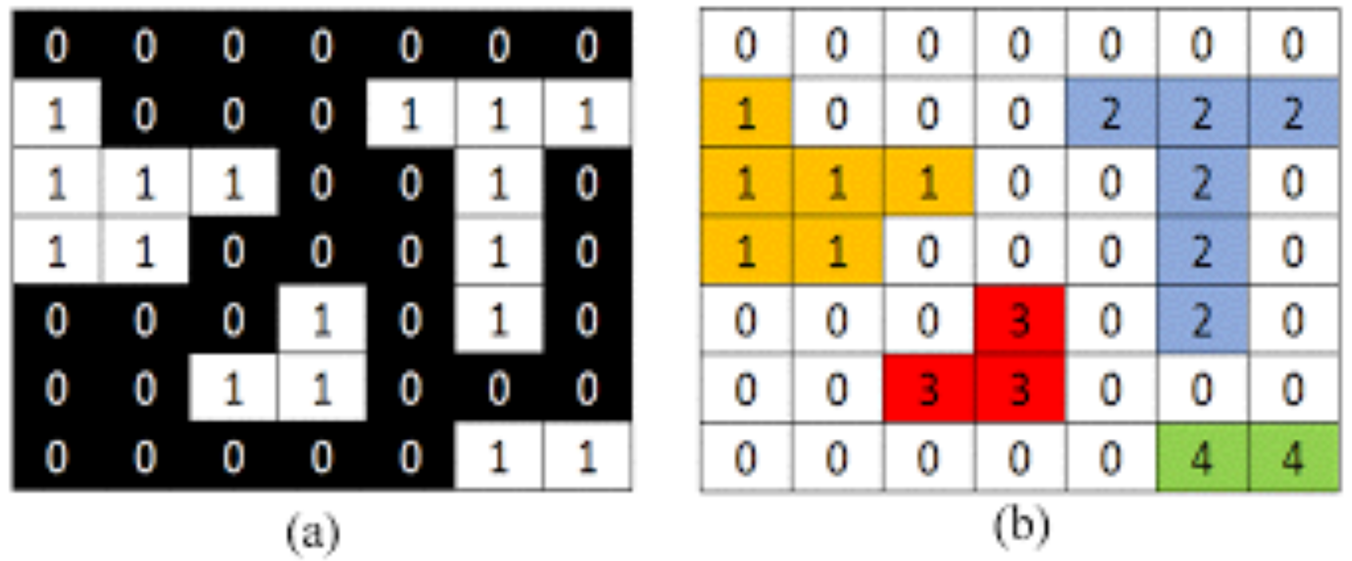
Segmentation



Thresholding



Connected components



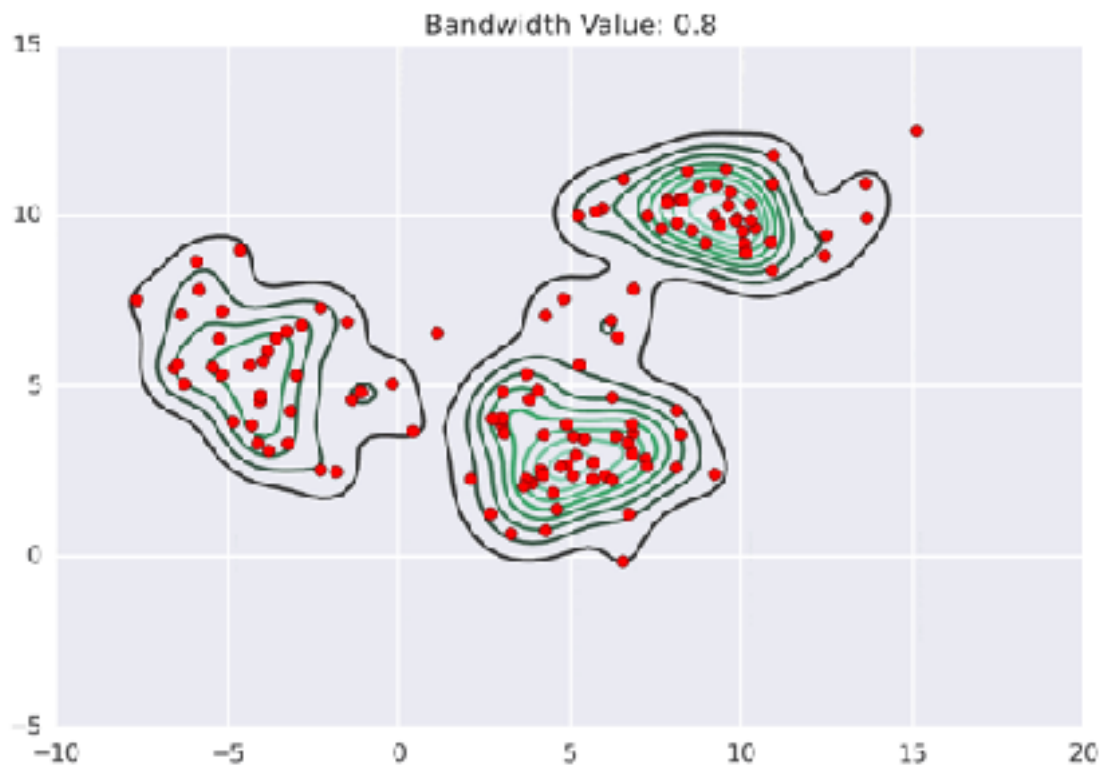
0	0	0	0	0	0	0
1	0	0	0	1	1	1
1	1	1	0	0	1	0
1	1	0	0	0	1	0
0	0	0	1	0	1	0
0	0	1	1	0	0	0
0	0	0	0	0	1	1

(a)

0	0	0	0	0	0	0
1	0	0	0	2	2	2
1	1	1	0	0	2	0
1	1	0	0	0	2	0
0	0	0	3	0	2	0
0	0	3	3	0	0	0
0	0	0	0	0	4	4

(b)

Clustering



Graph-based methods

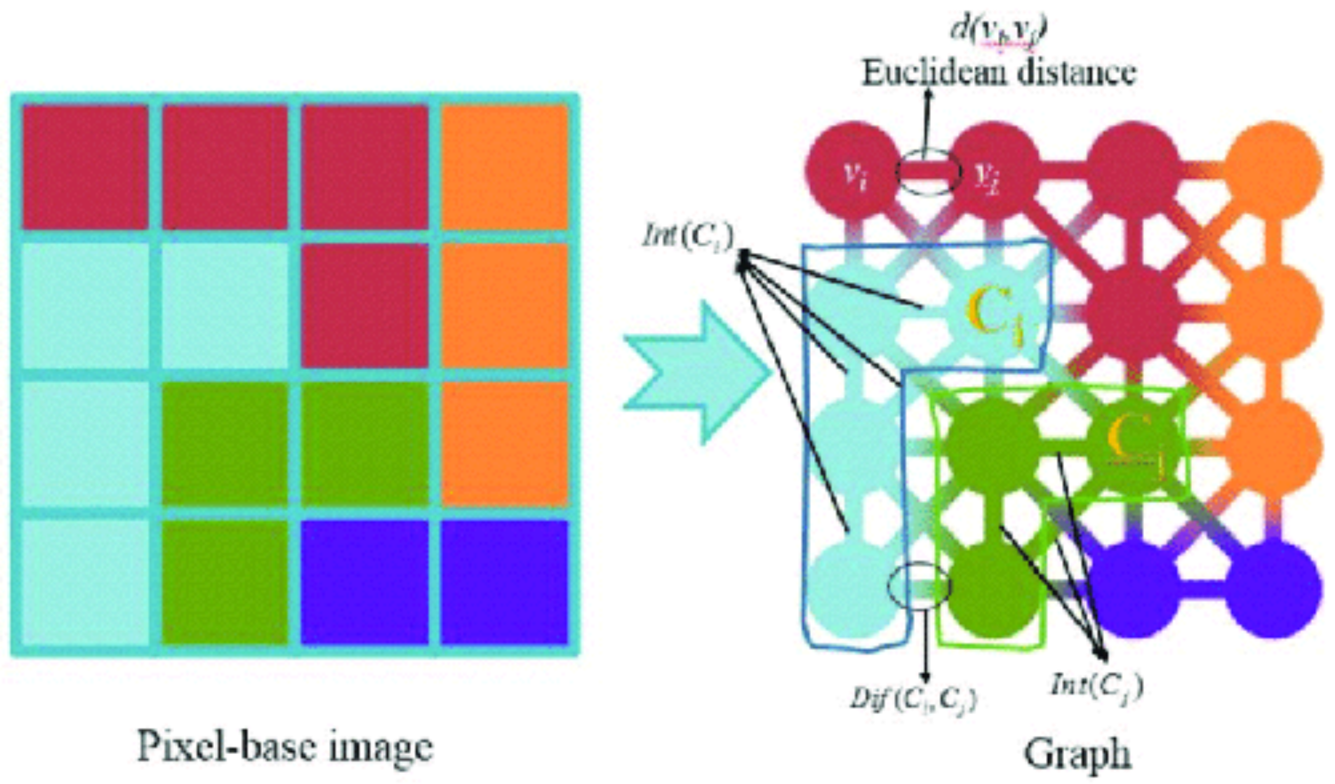
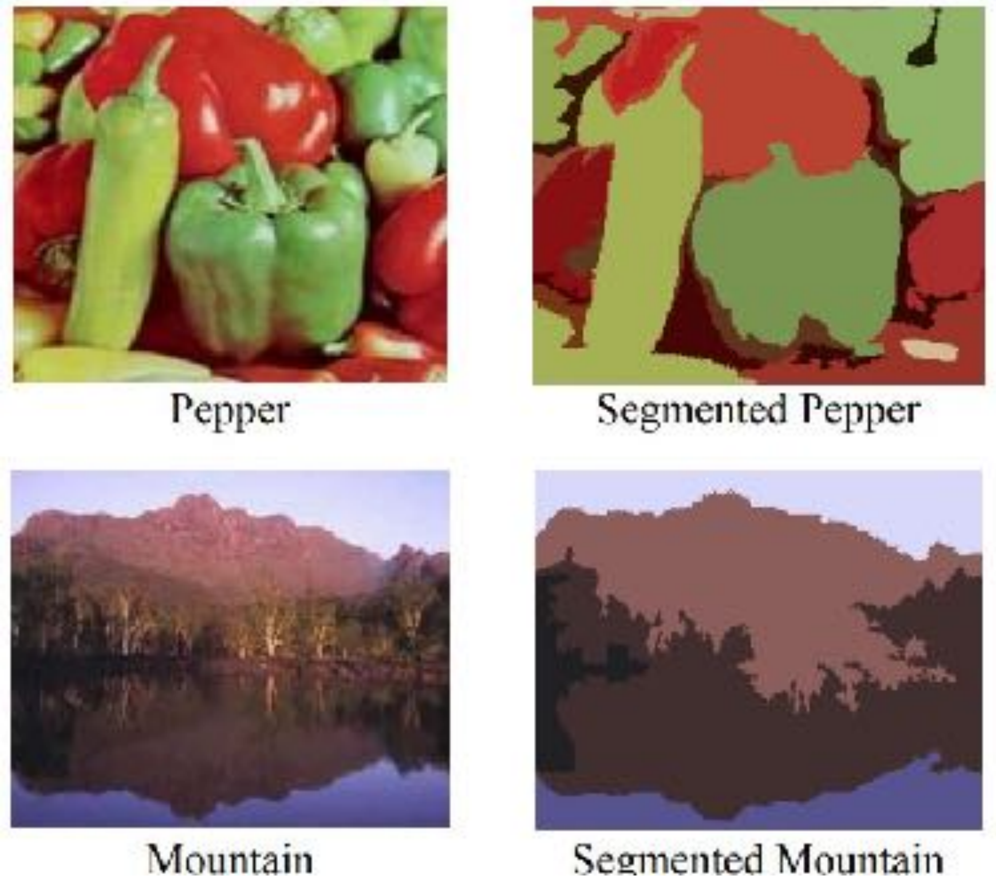
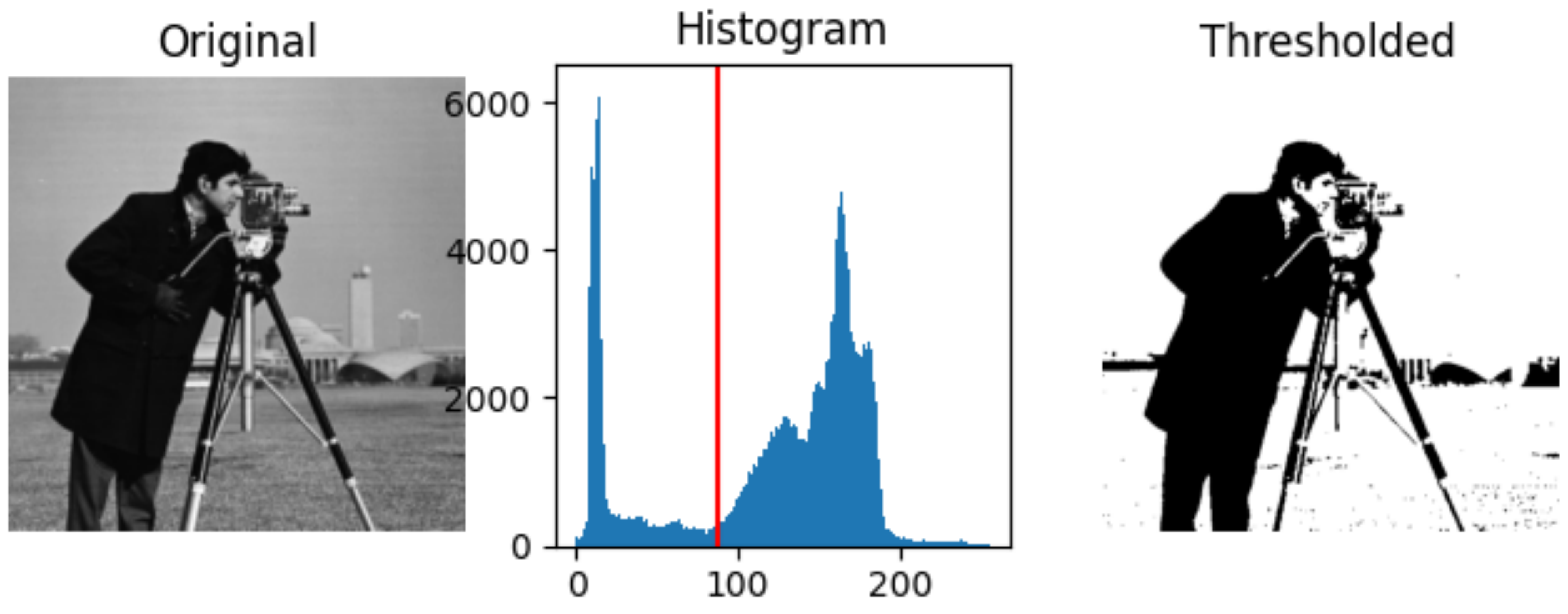


Image Segmentation

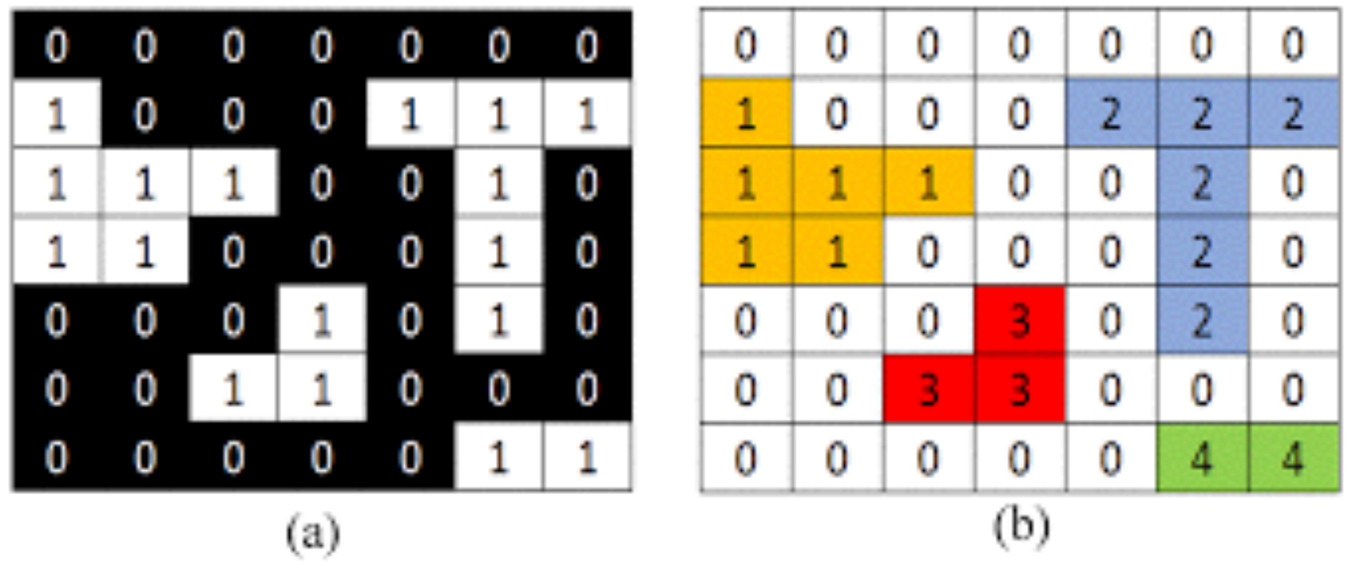
Segmentation



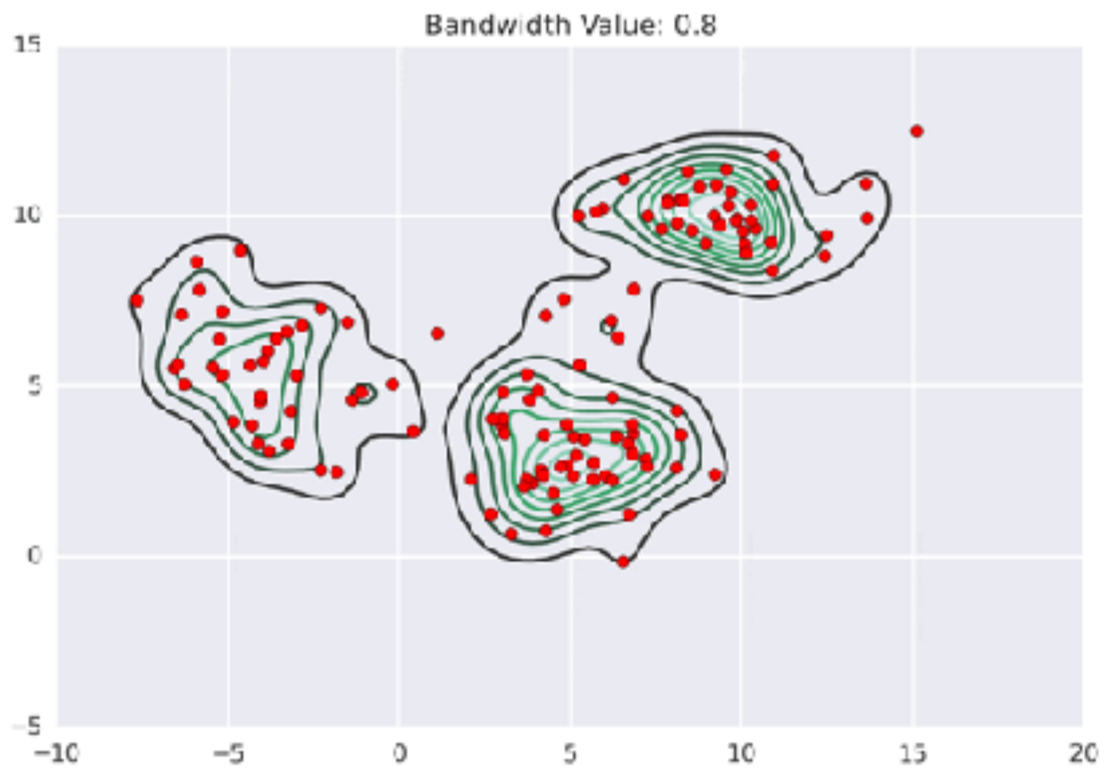
Thresholding



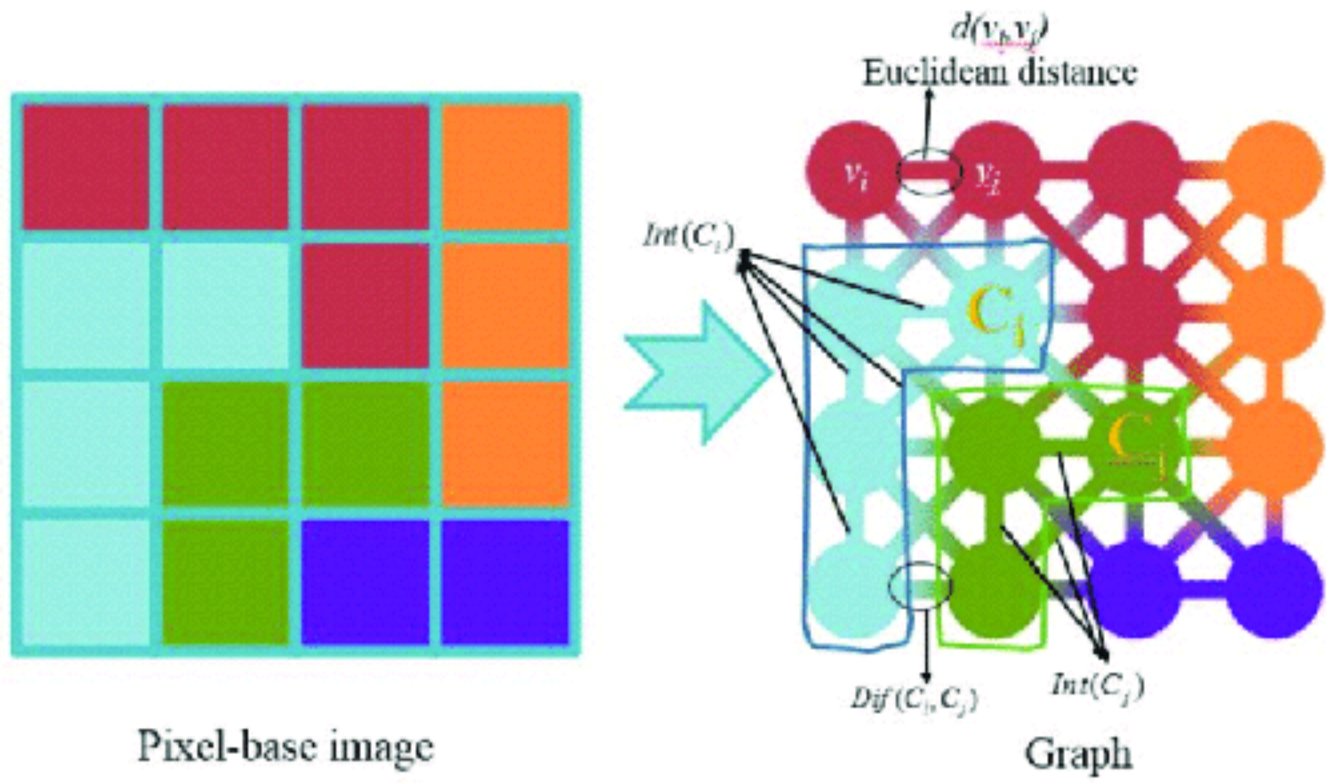
Connected components



Clustering



Graph-based methods



Evaluation

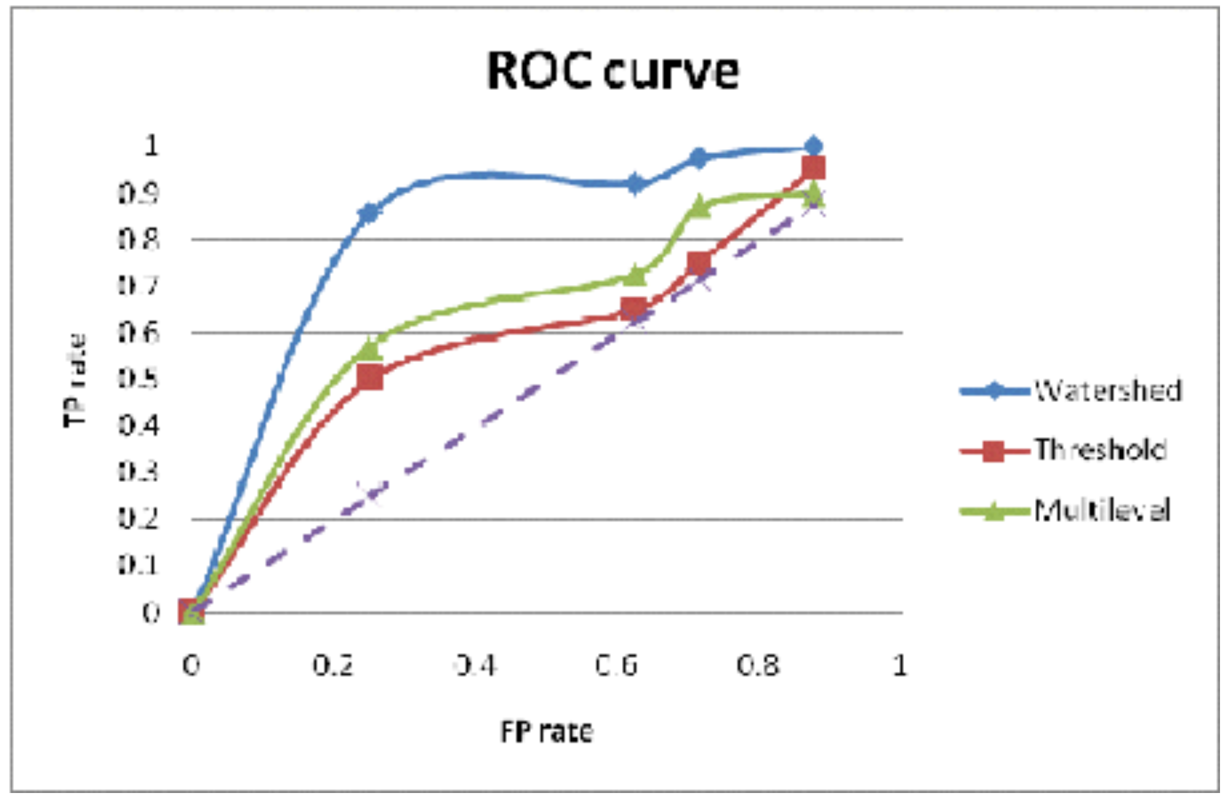


Image Transformation

Image Transformation

Linear transformations

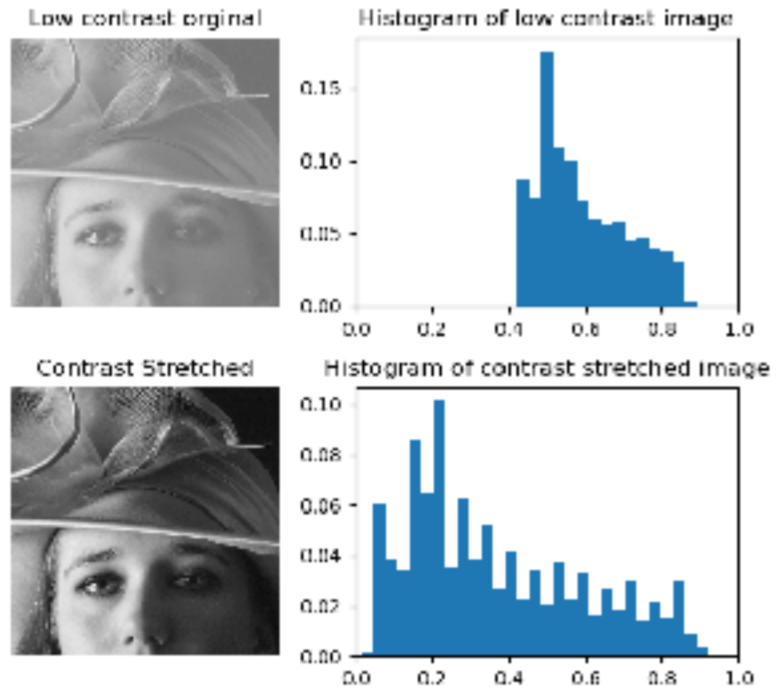
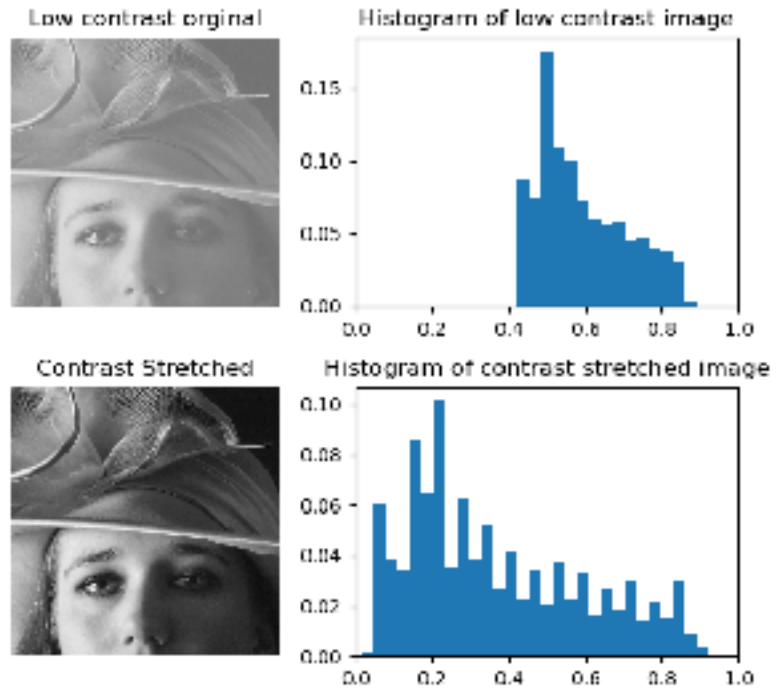
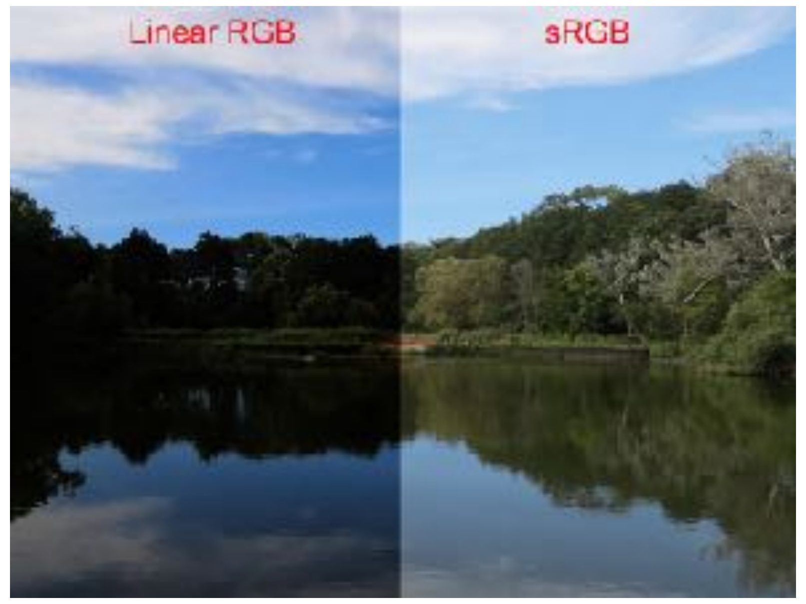


Image Transformation

Linear transformations



Non-linear transformations



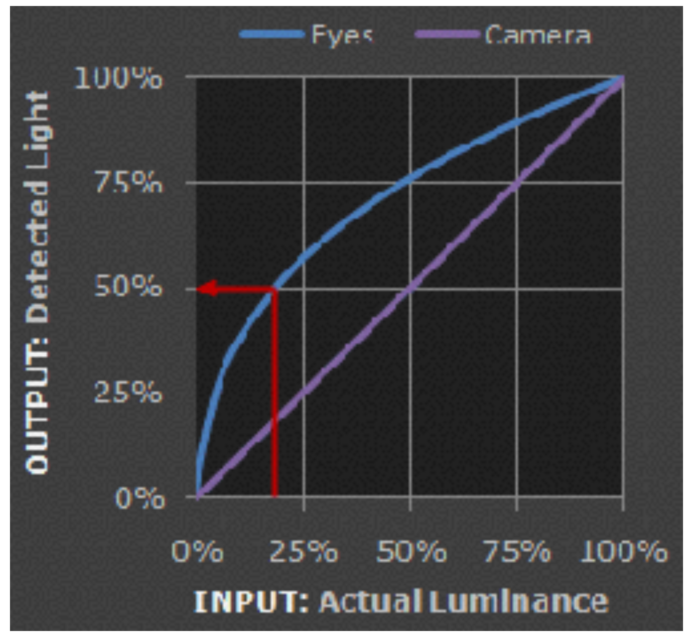
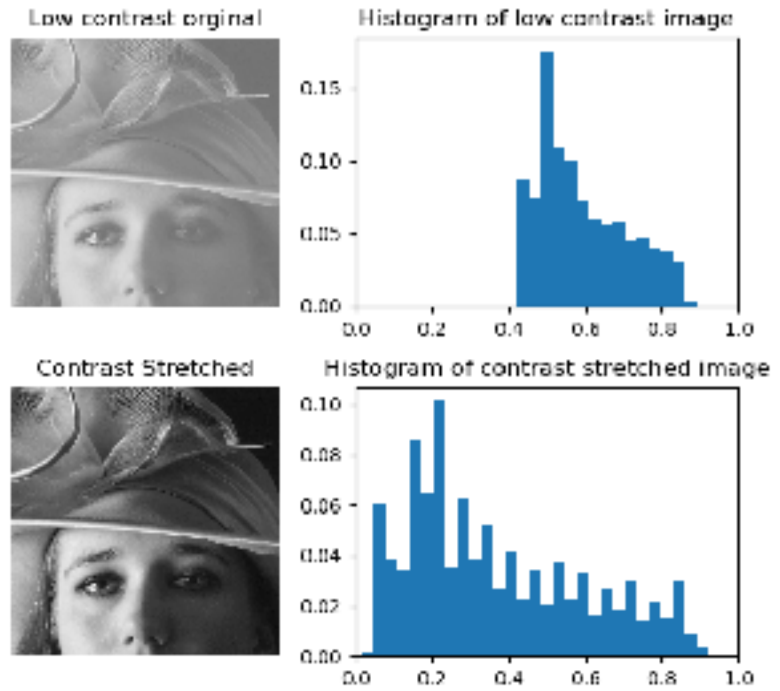
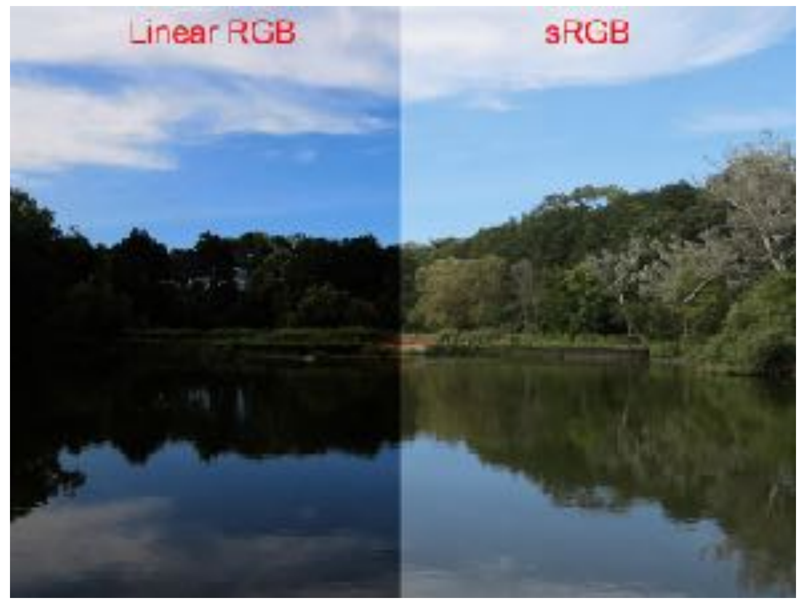


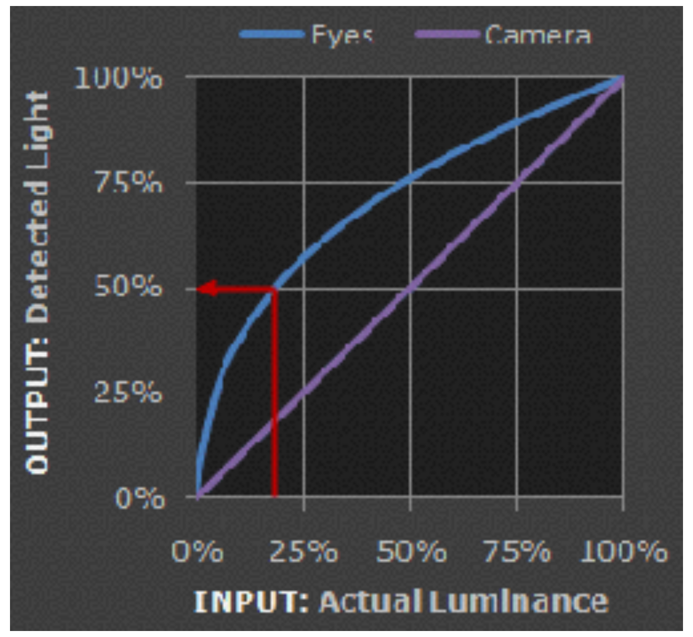
Image Transformation

Linear transformations

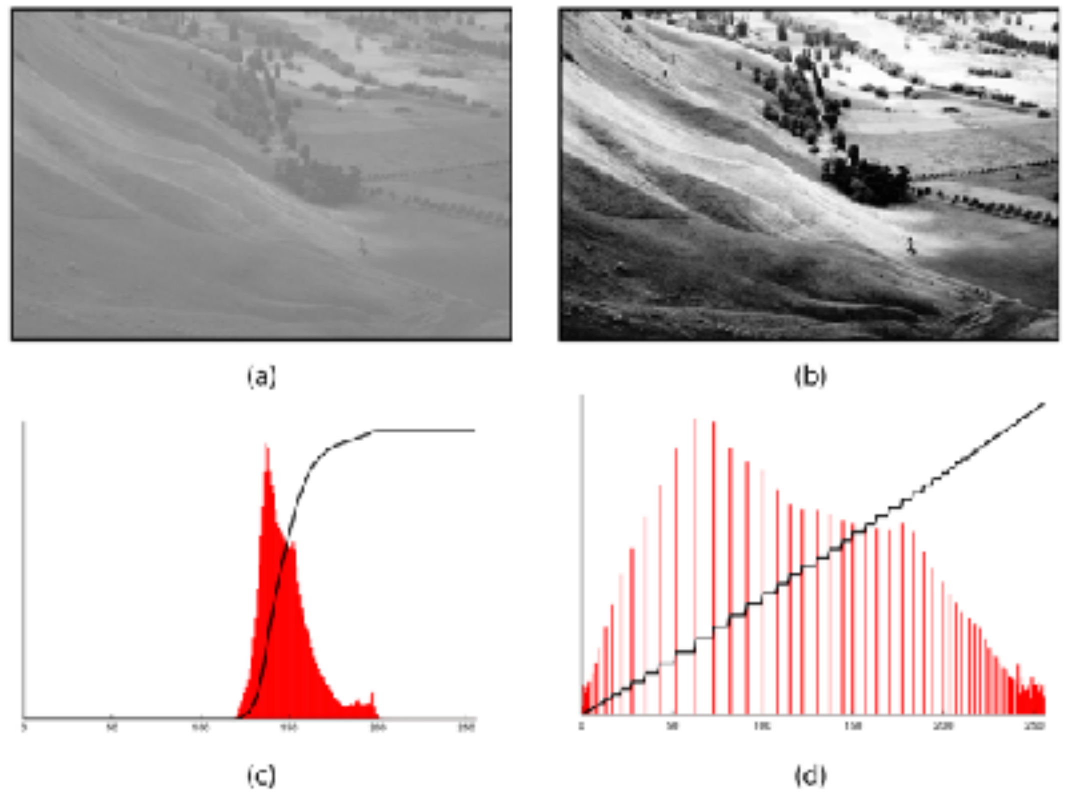


Non-linear transformations





Histogram equalization



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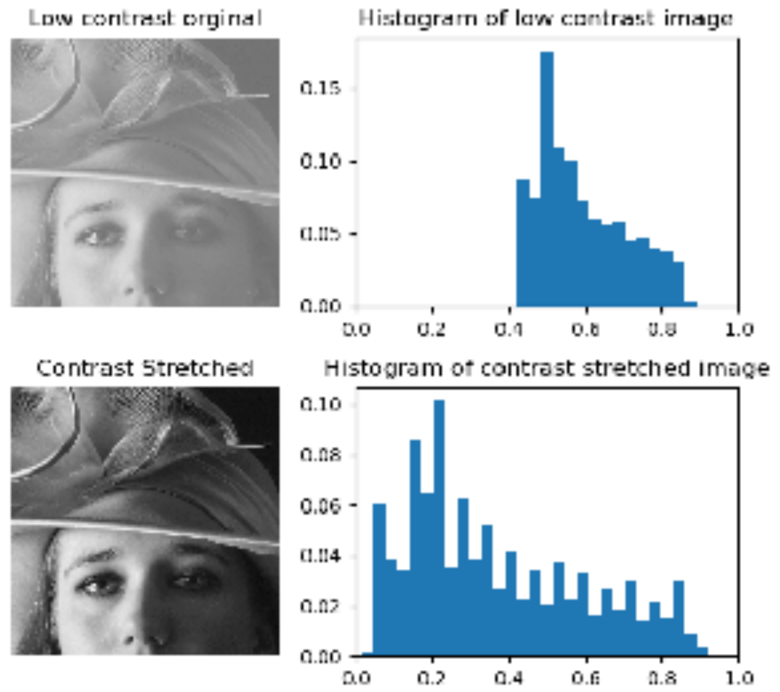
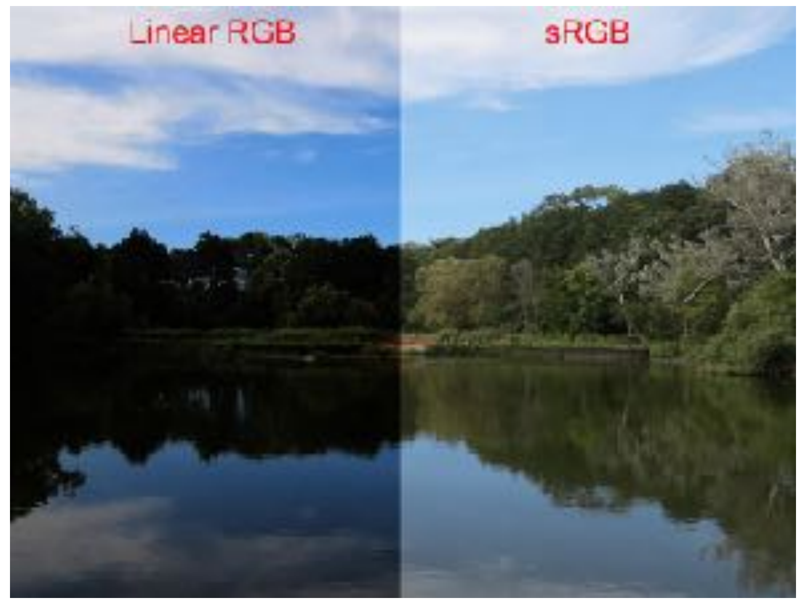
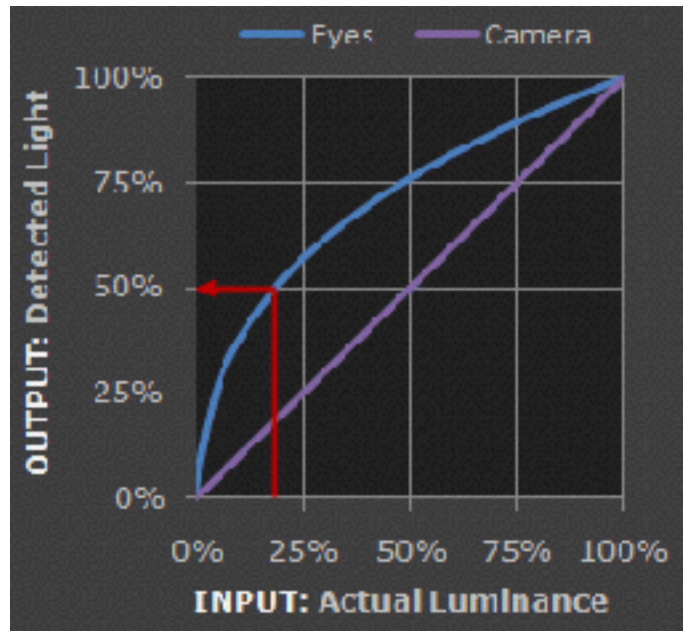
Linear transformations

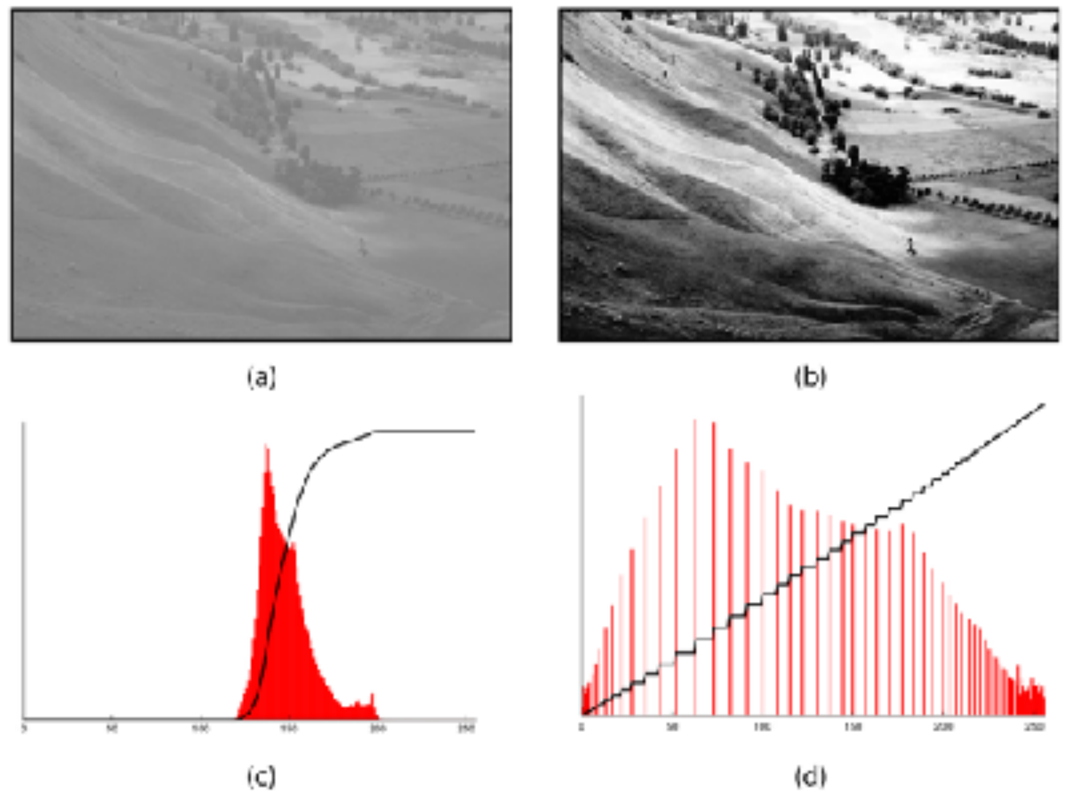


Non-linear transformations





Histogram equalization



Affine transformations

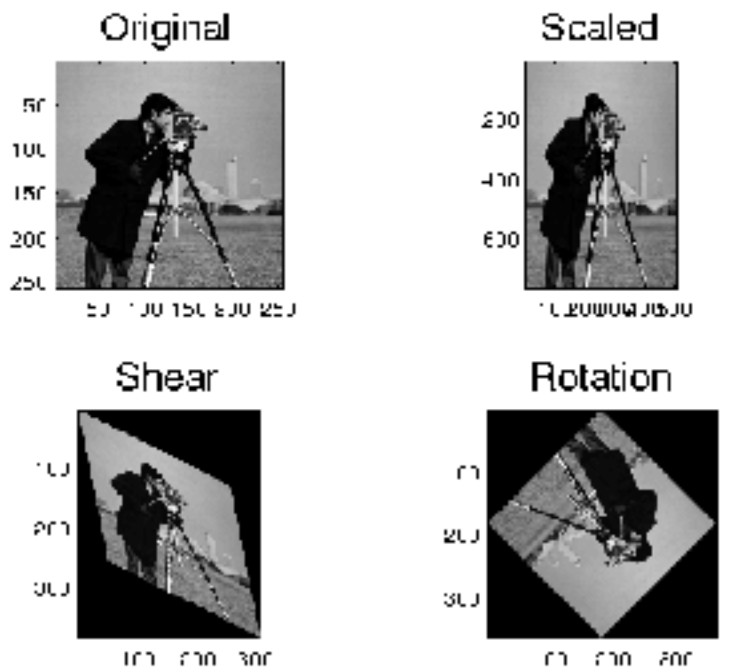
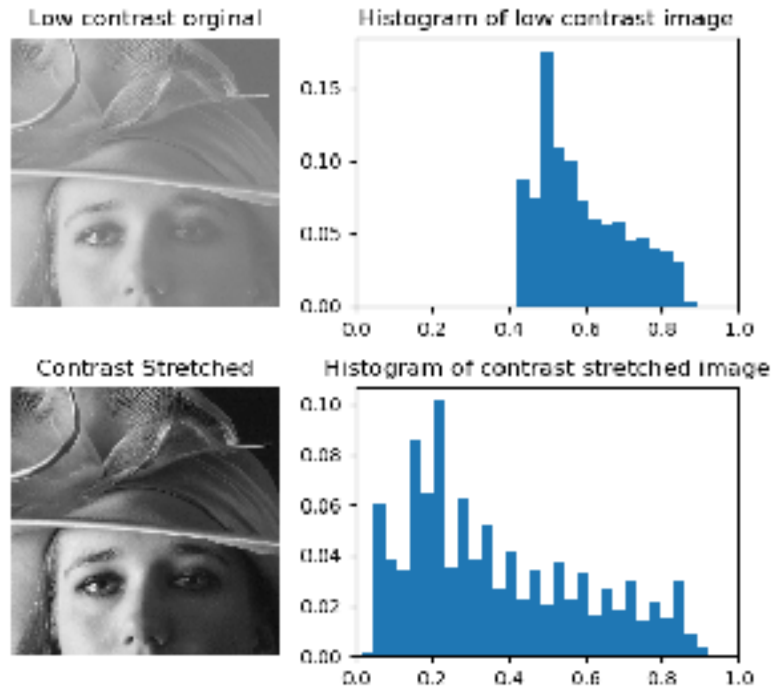
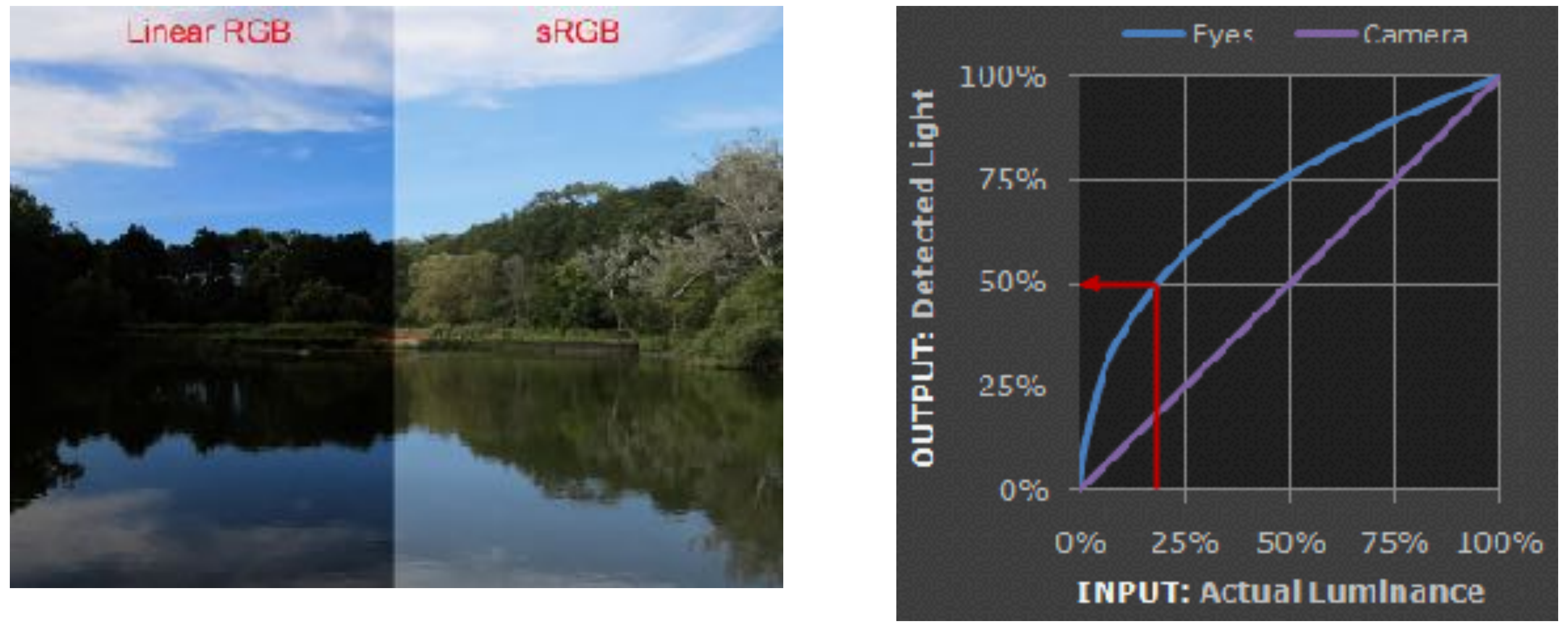


Image Transformation

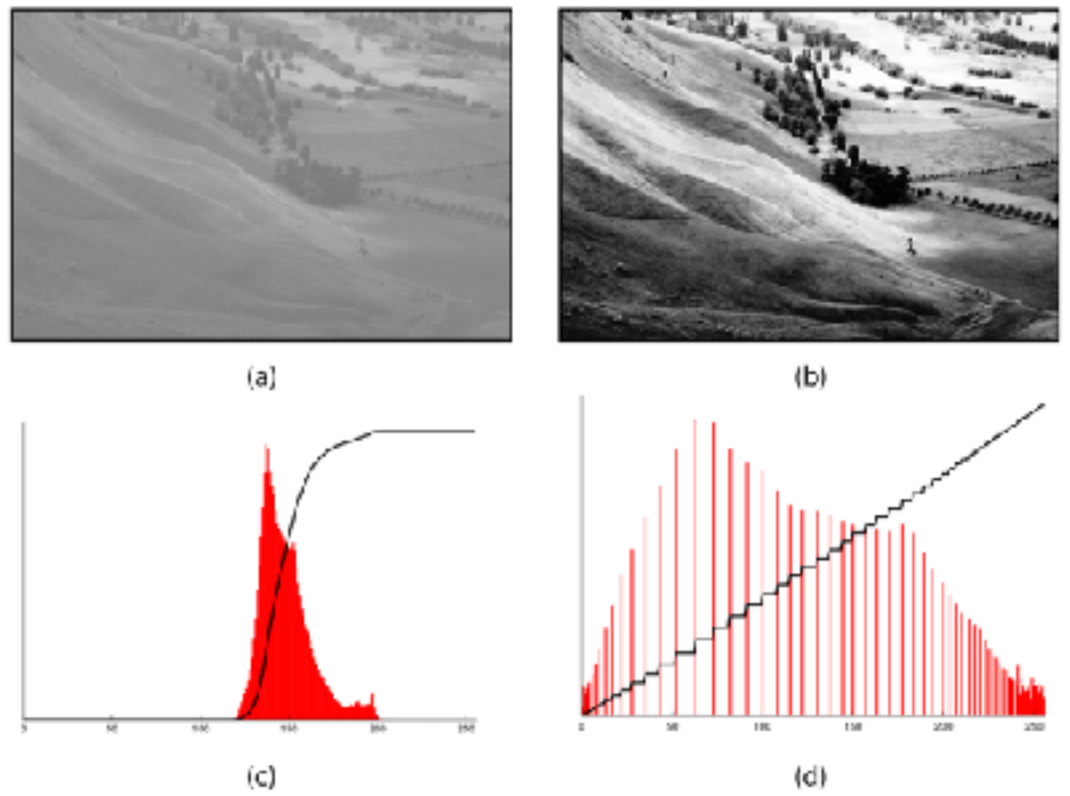
Linear transformations



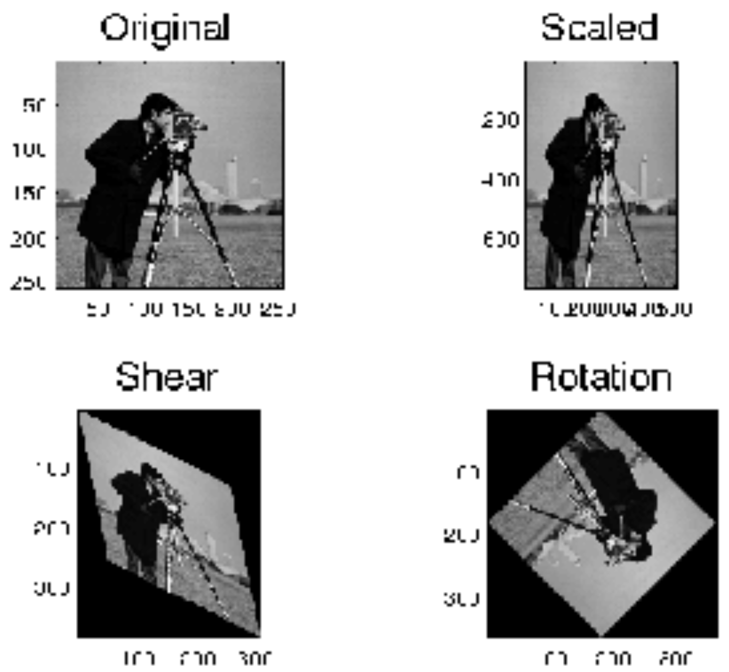
Non-linear transformations



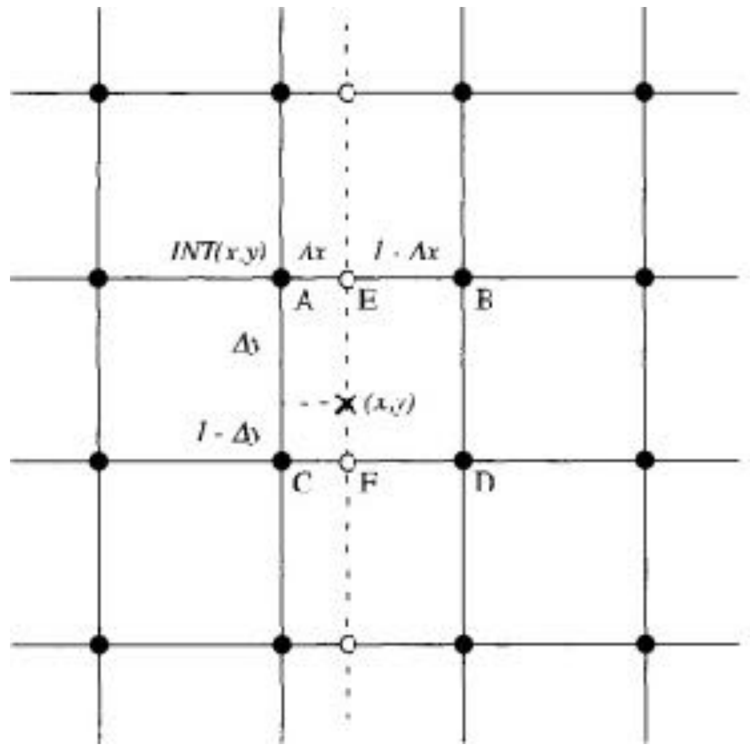
Histogram equalization



Affine transformations



Interpolation

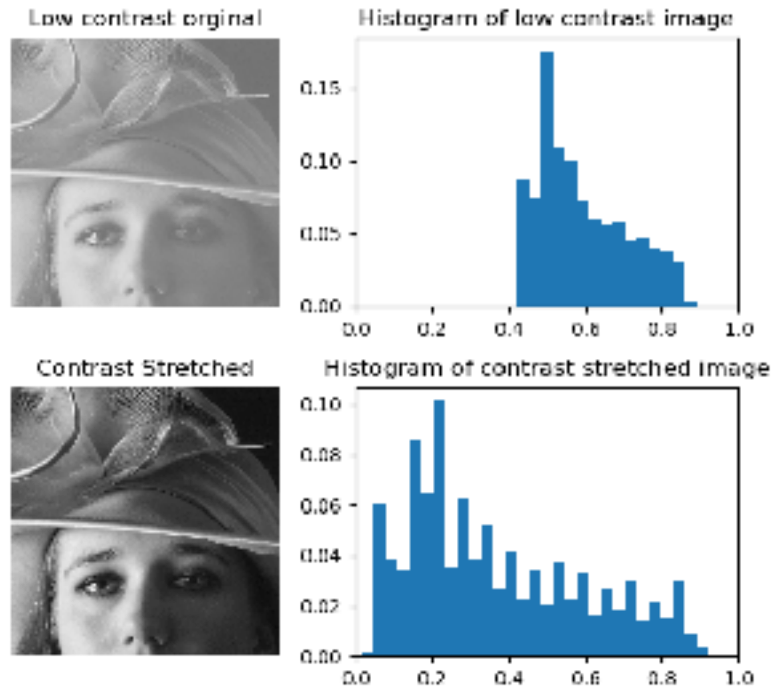


bilinear resampling:

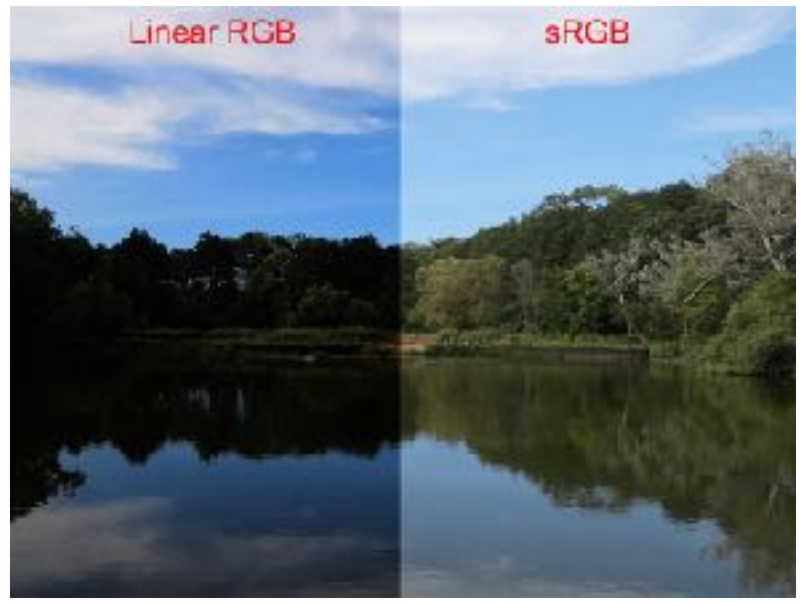
$$DN_E = \Delta x DN_B + (1 - \Delta x) DN_A$$
$$DN_F = \Delta x DN_D + (1 - \Delta x) DN_C$$
$$DN(x, y) = \Delta y DN_F + (1 - \Delta y) DN_E$$

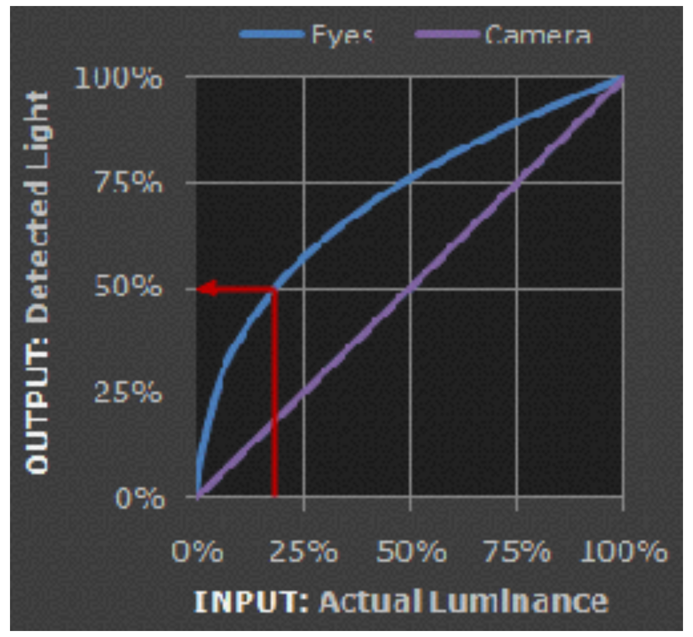
Image Transformation

Linear transformations

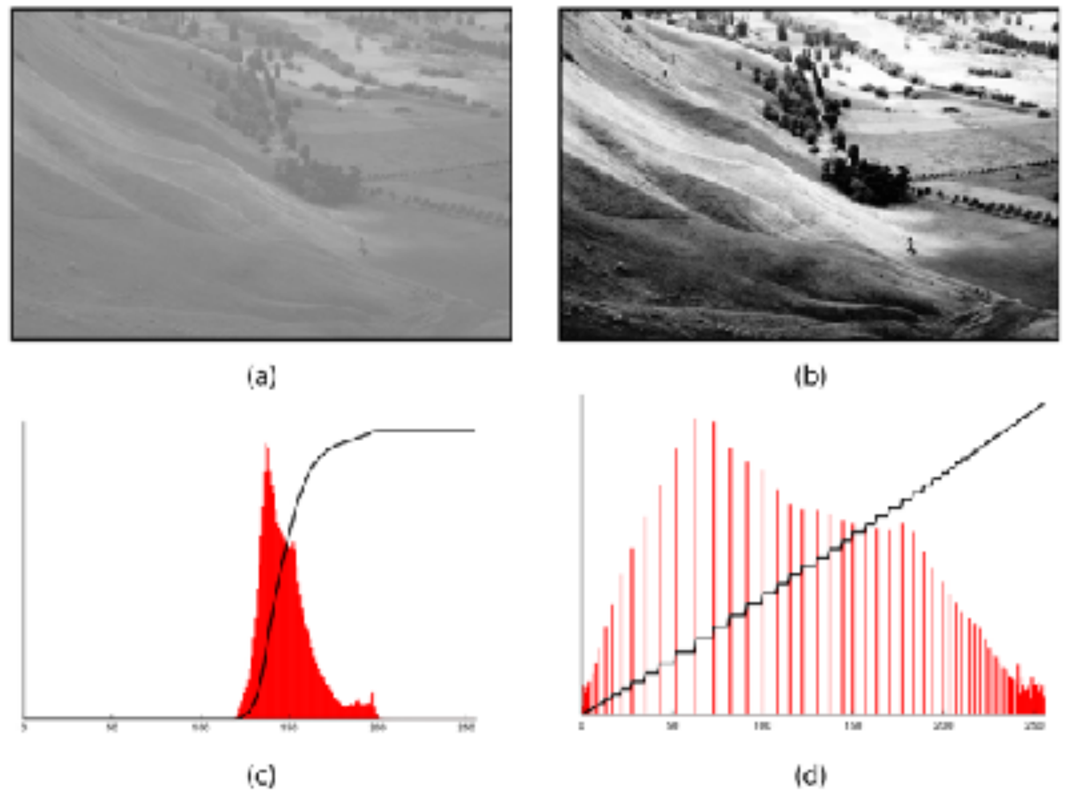


Non-linear transformations

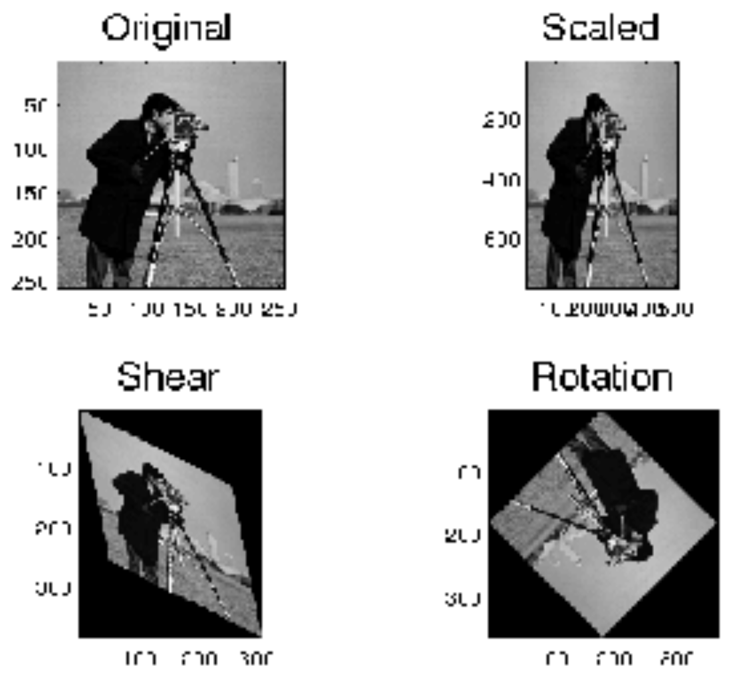




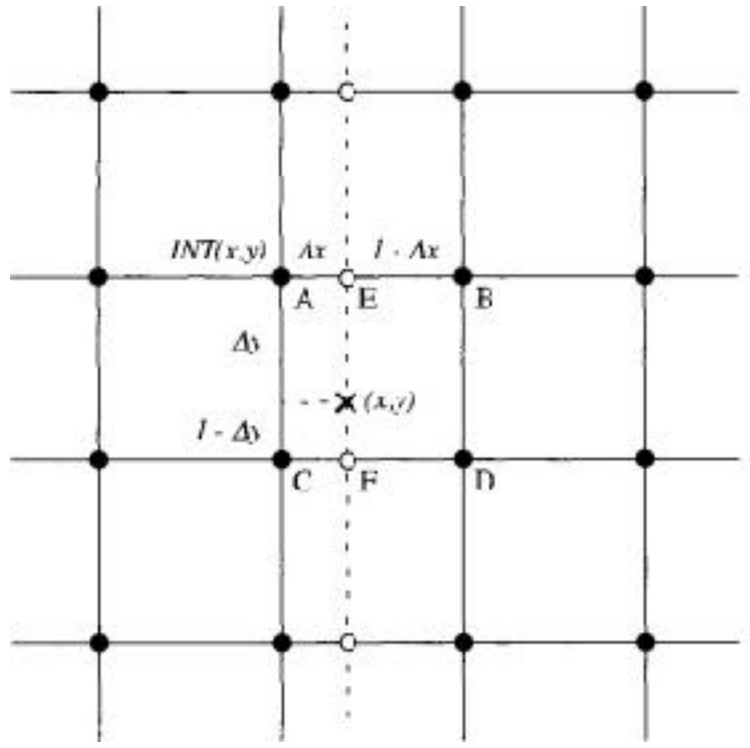
Histogram equalization



Affine transformations



Interpolation



bilinear resampling:

$$DN_E = \Delta x DN_B + (1-\Delta x) DN_A$$
$$DN_F = \Delta x DN_D + (1-\Delta x) DN_C$$
$$DN(x,y) = \Delta y DN_F + (1-\Delta y) DN_E$$

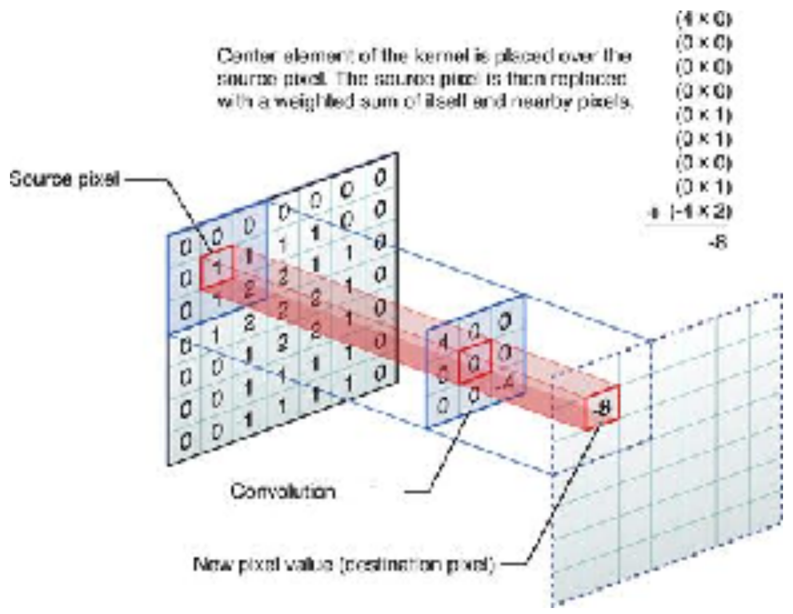
Warping and morphing

UCL

Filtering in Spatial Domain

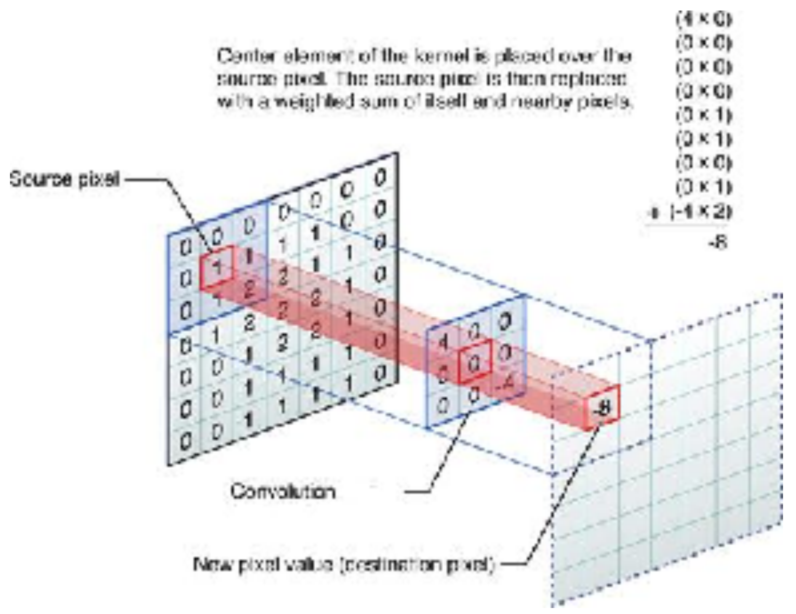
Filtering in Spatial Domain

Convolution filters

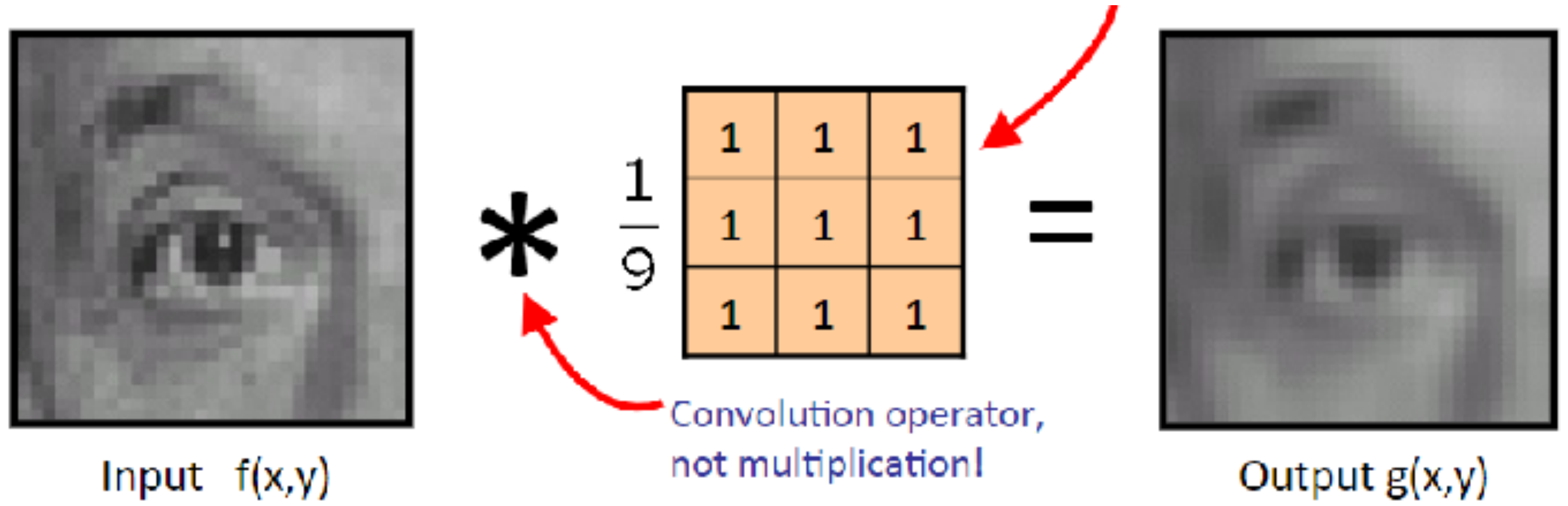


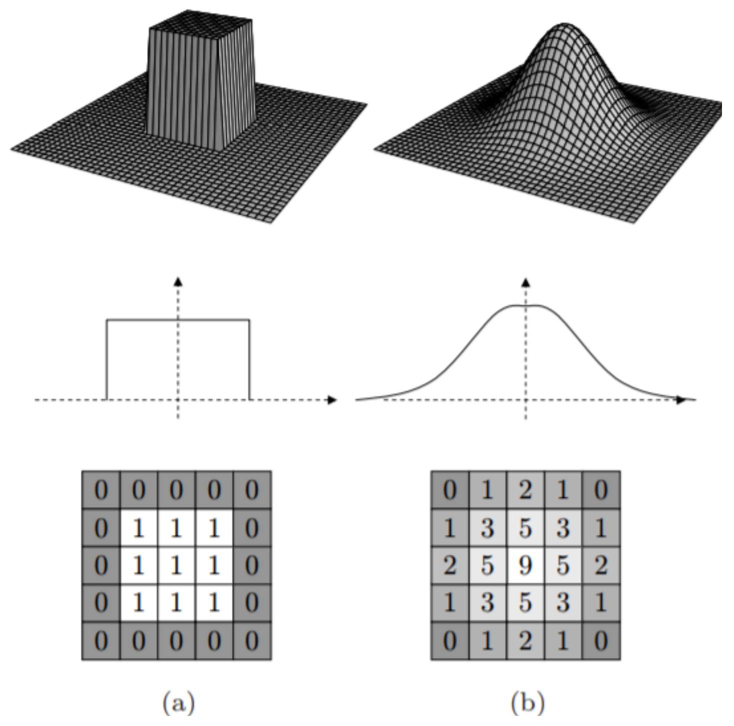
Filtering in Spatial Domain

Convolution filters



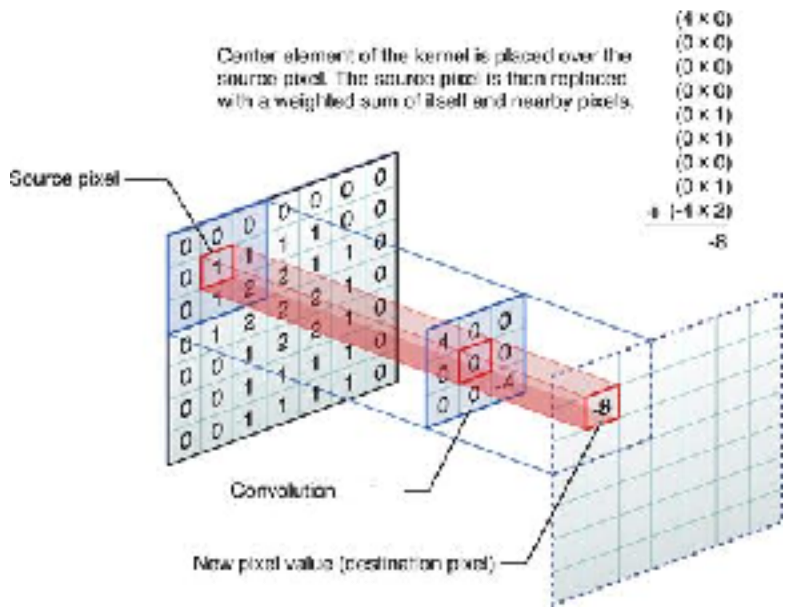
Smoothing filters



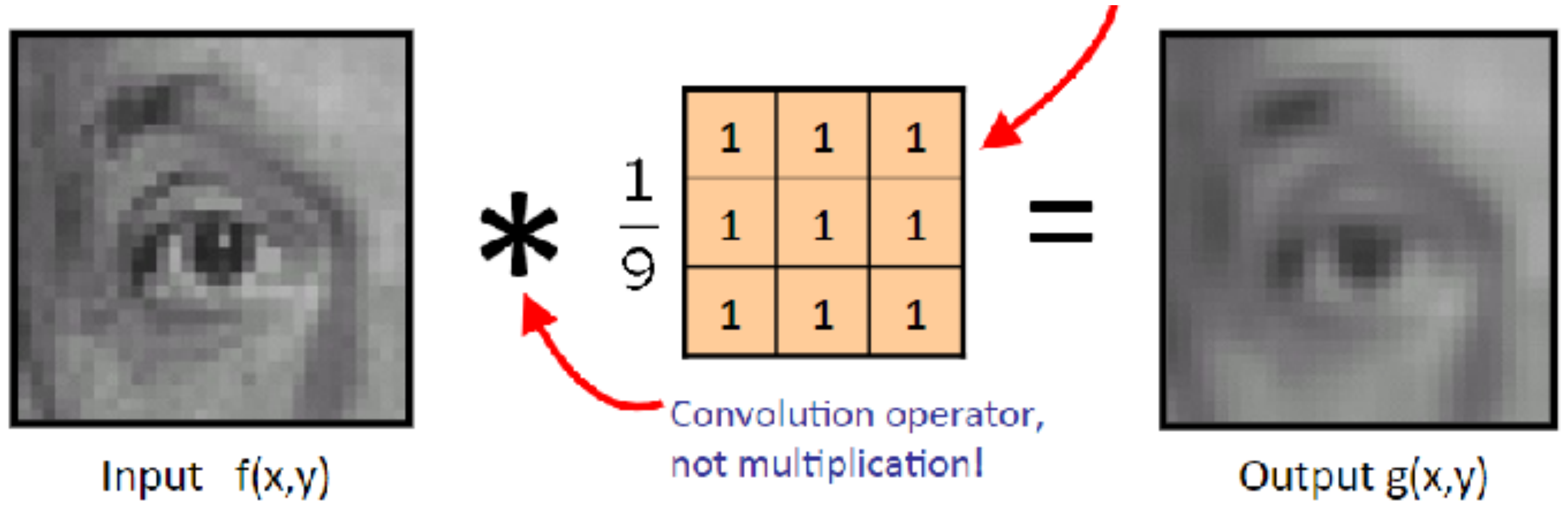


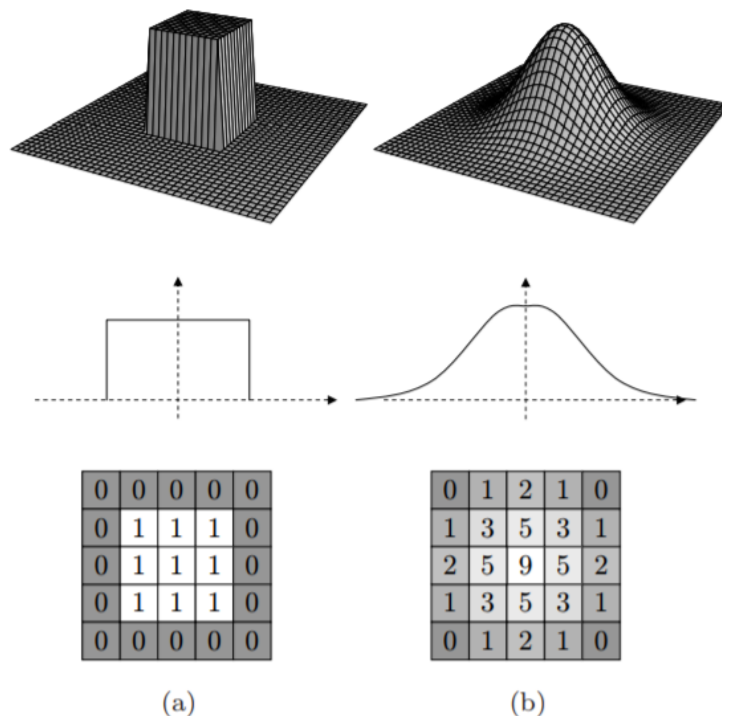
Filtering in Spatial Domain

Convolution filters



Smoothing filters





Derivative filters

-1	0	+1
-2	0	2
-1	0	+1

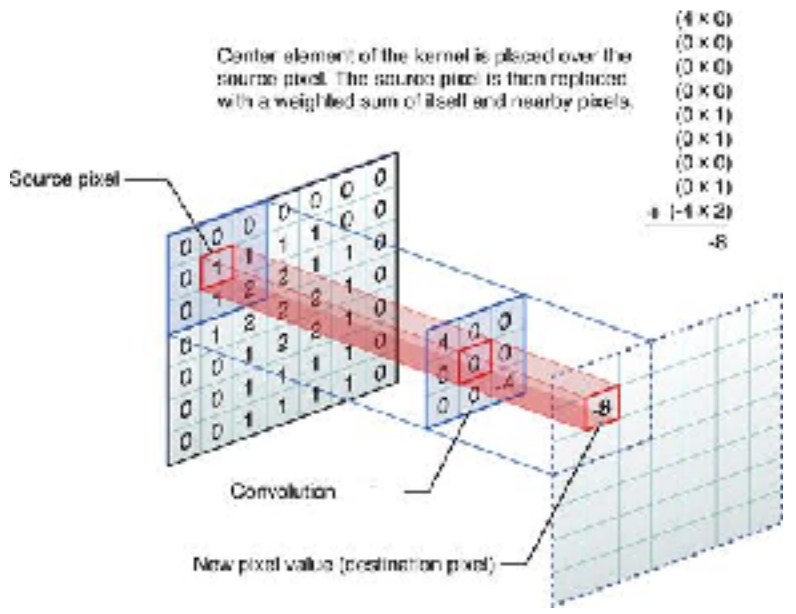
Gx

+1	+2	+1
0	0	0
-1	-2	-1

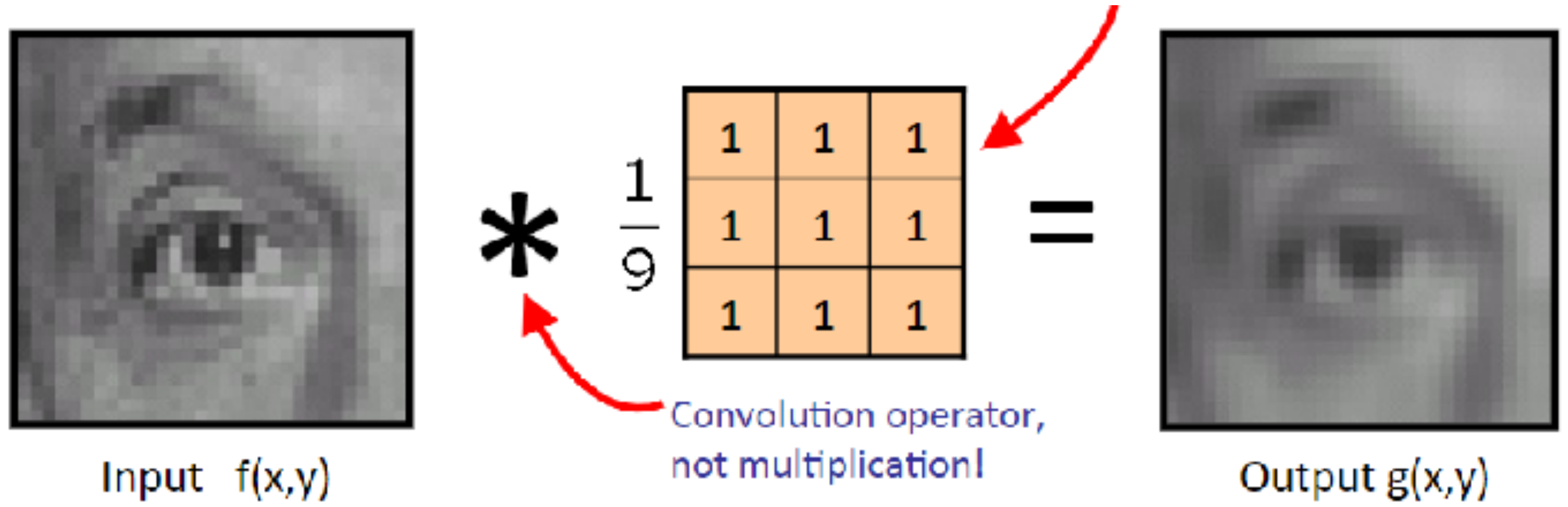
Gy

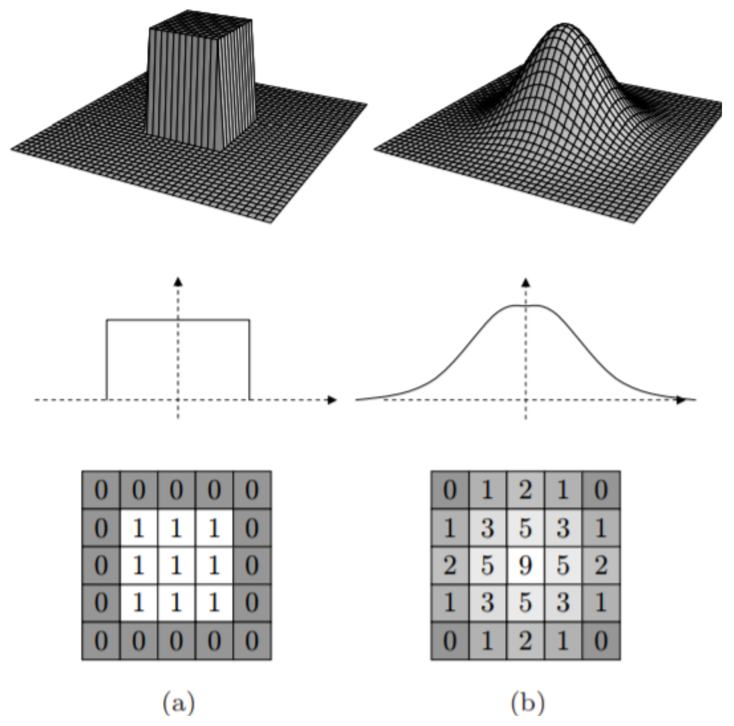
Filtering in Spatial Domain

Convolution filters



Smoothing filters





Derivative filters

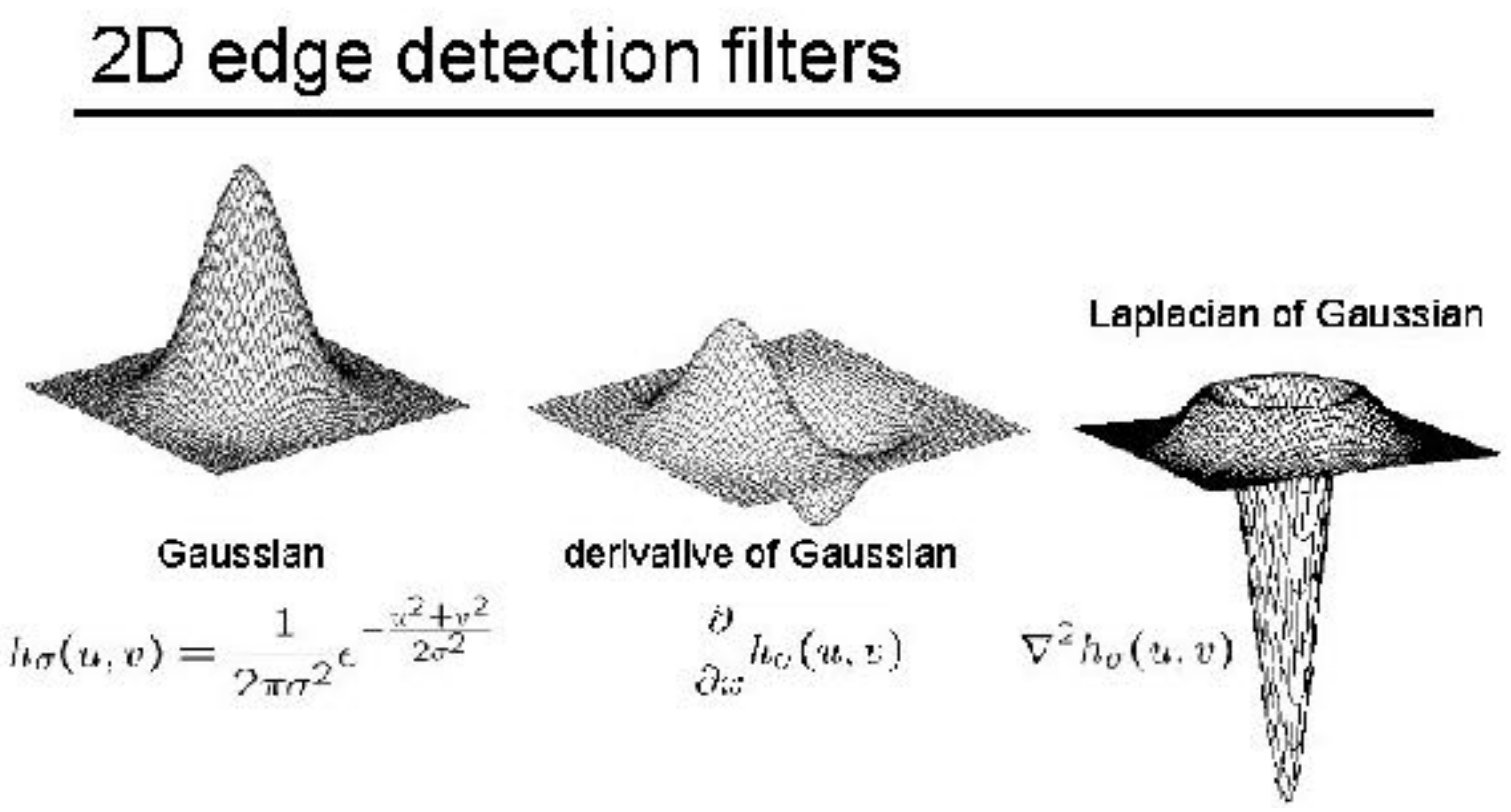
-1	0	+1
-2	0	2
-1	0	+1

Gx

+1	+2	+1
0	0	0
-1	-2	-1

Gy

Laplacian of Gaussian

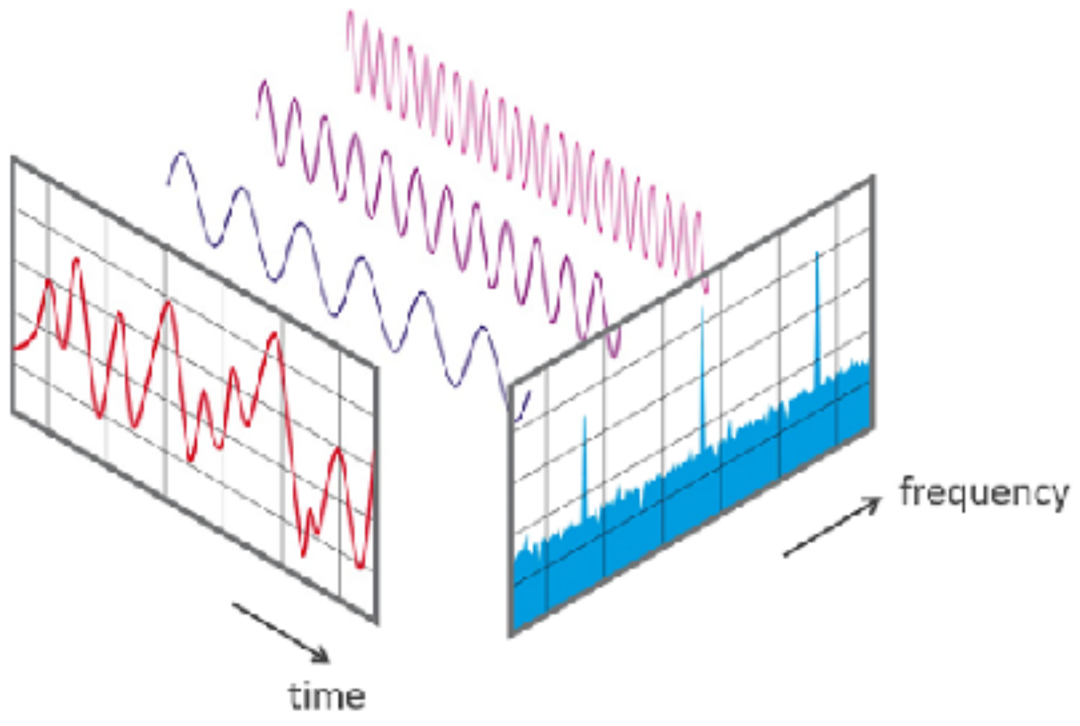


0	0	-1	0	0
0	-1	-2	-1	0
-1	-2	16	-2	-1
0	-1	-2	-1	0
0	0	-1	0	0

Filtering in Spectral Domain

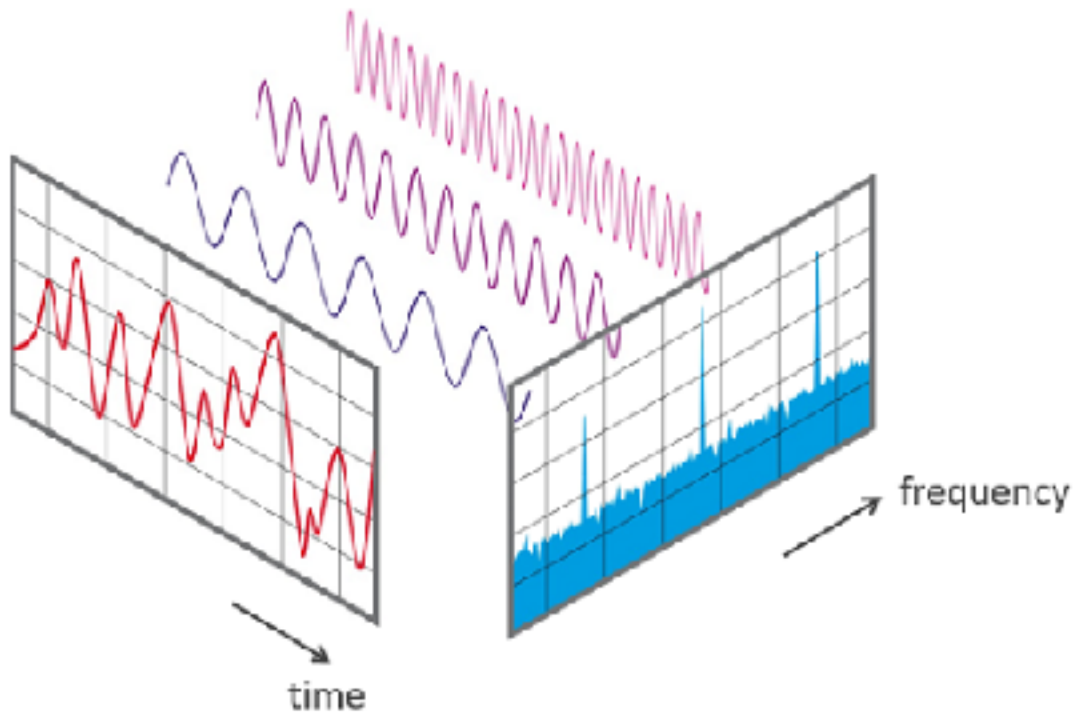
Filtering in Spectral Domain

Fourier transform

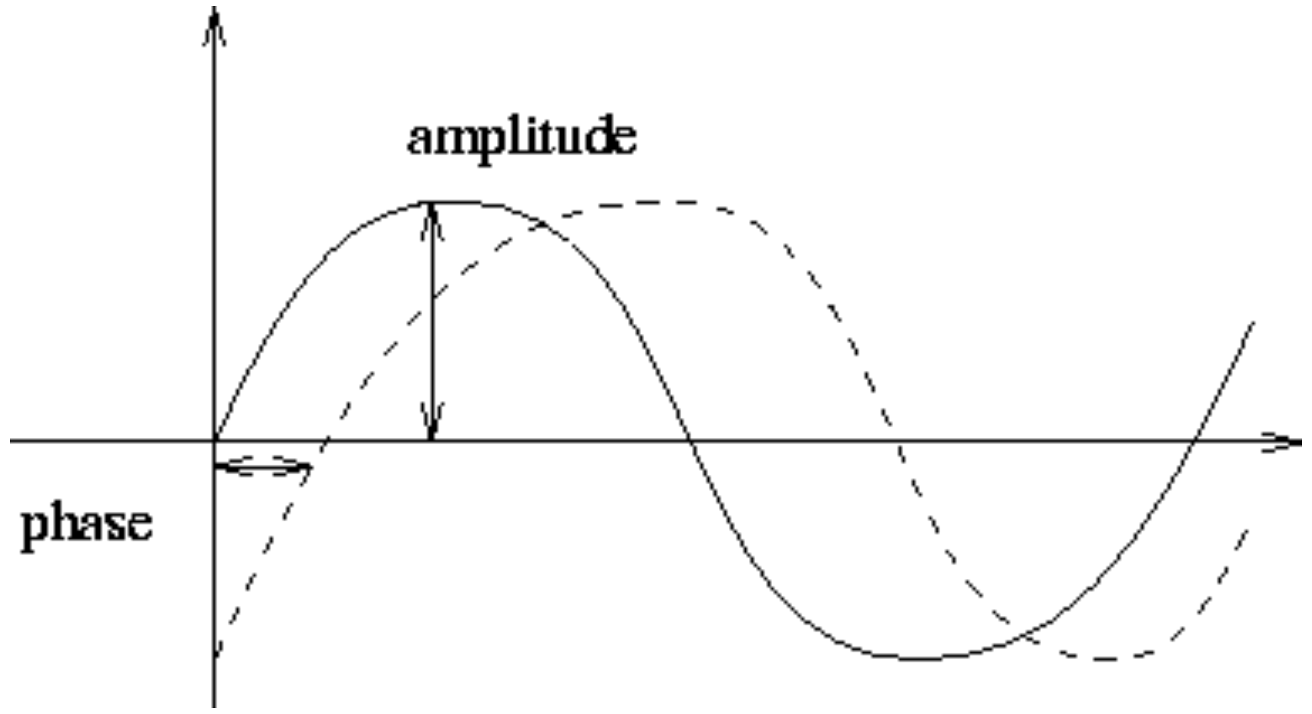


Filtering in Spectral Domain

Fourier transform

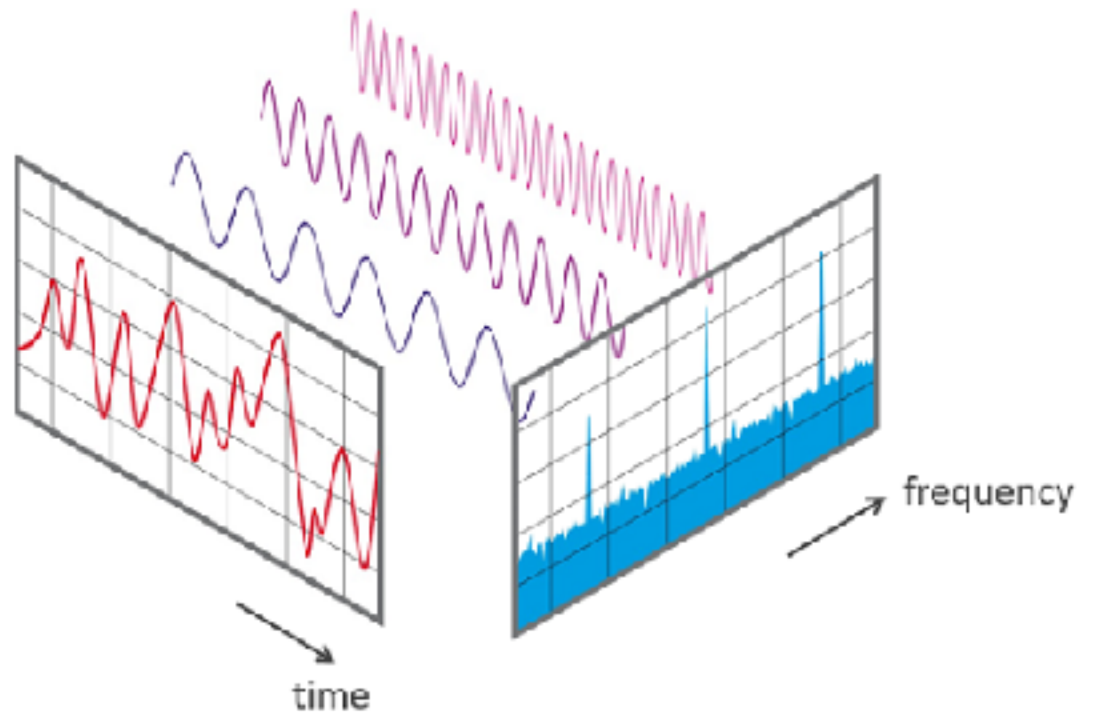


Magnitude and Phase

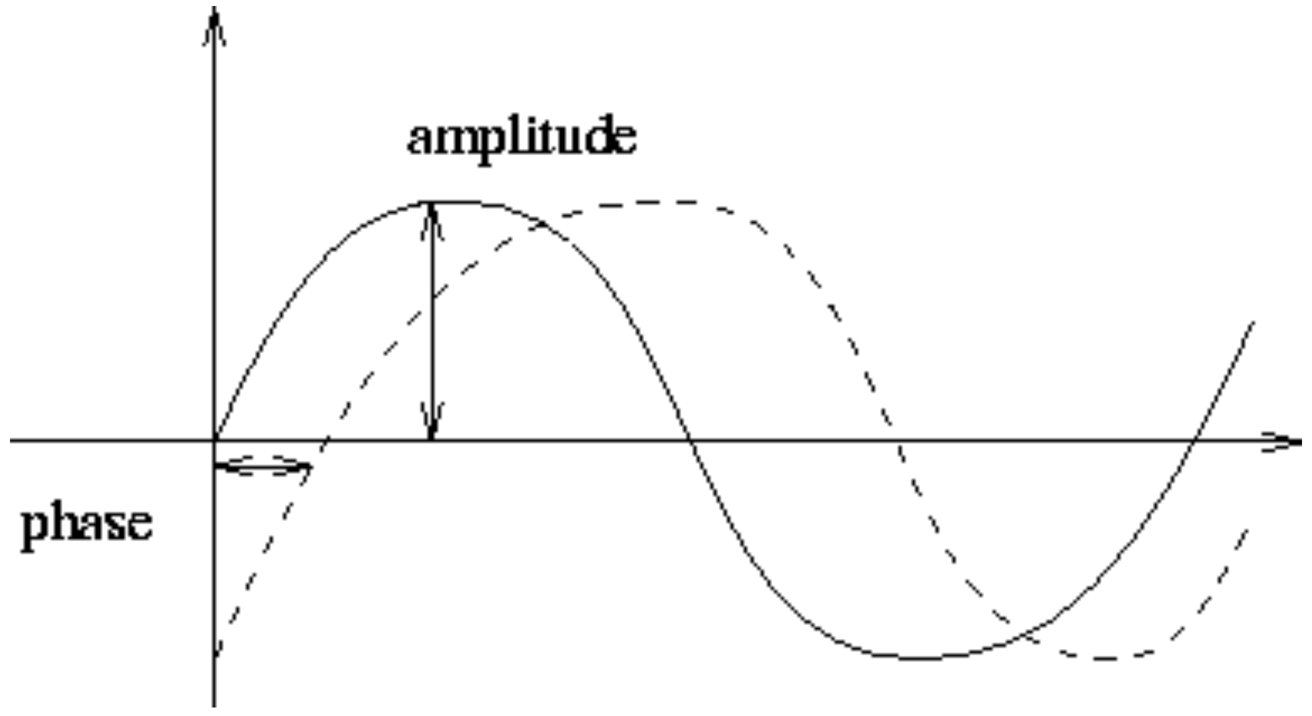


Filtering in Spectral Domain

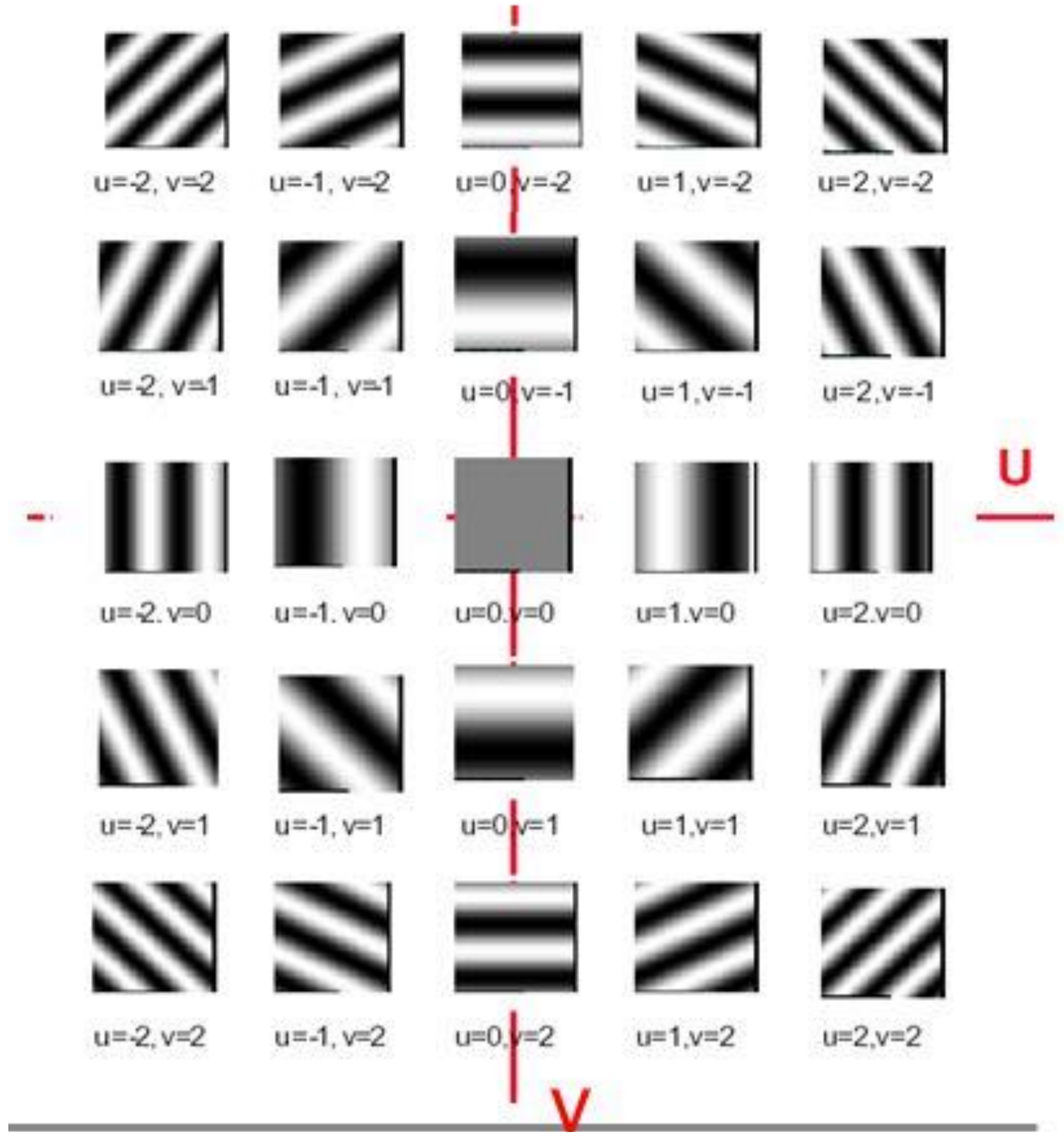
Fourier transform



Magnitude and Phase

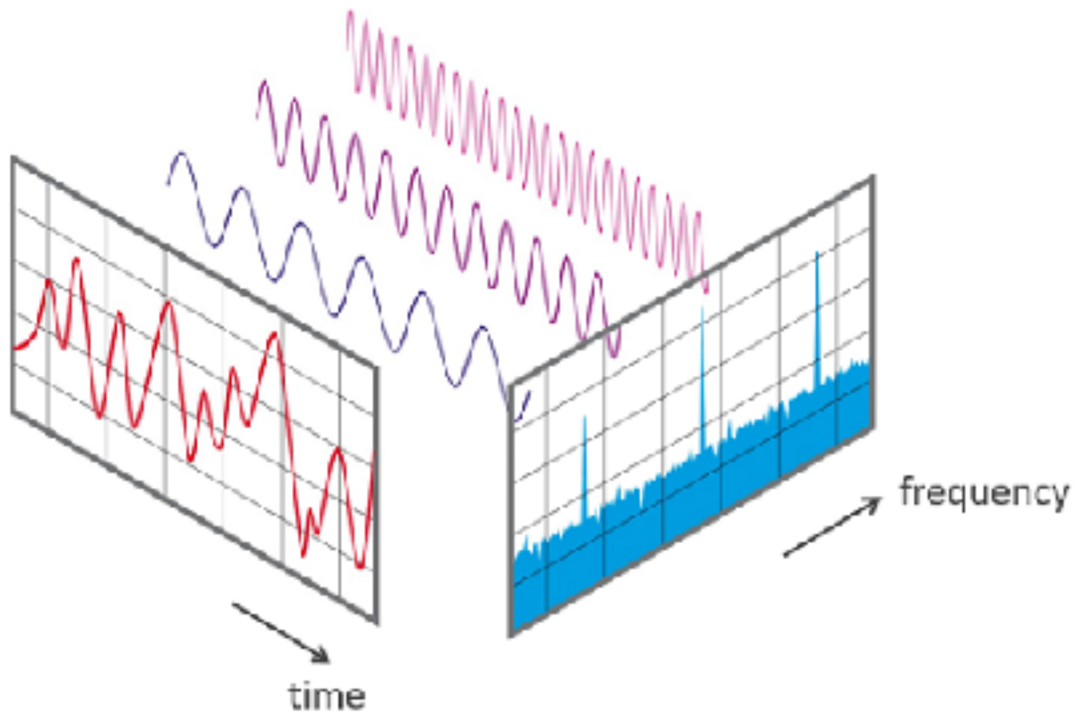


Fourier basis functions

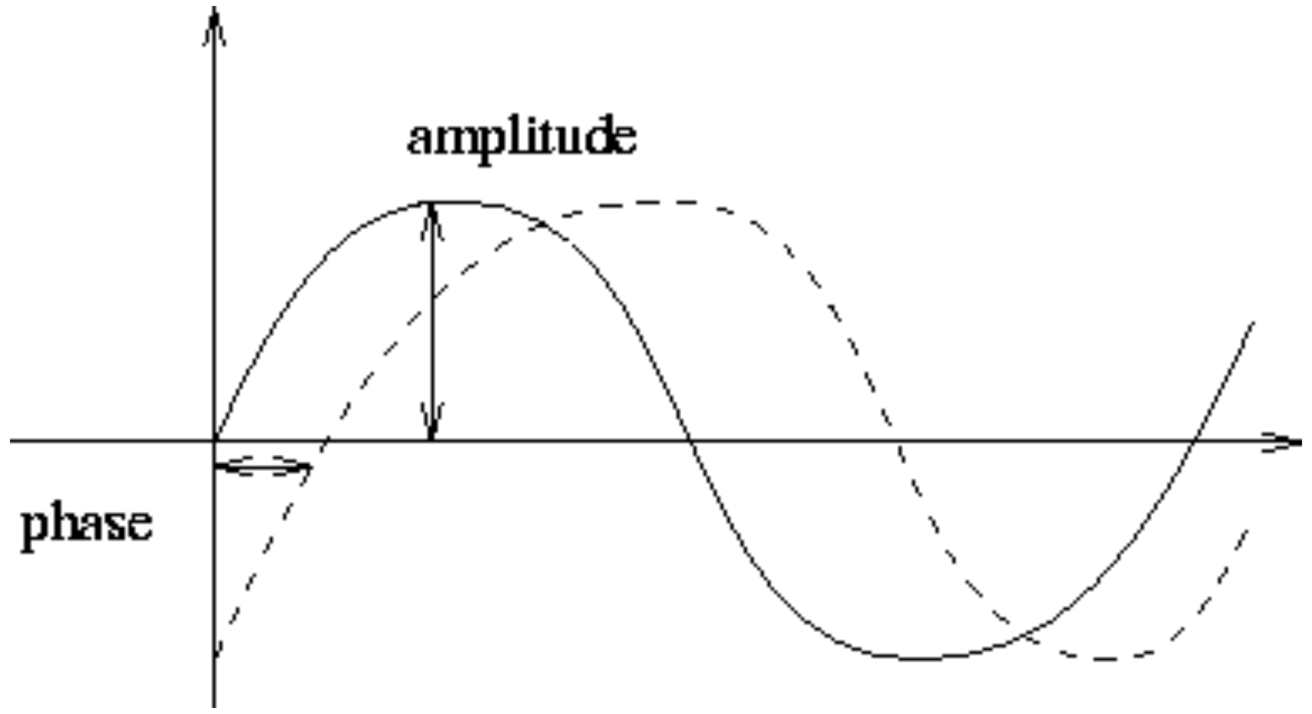


Filtering in Spectral Domain

Fourier transform



Magnitude and Phase



Fourier basis functions

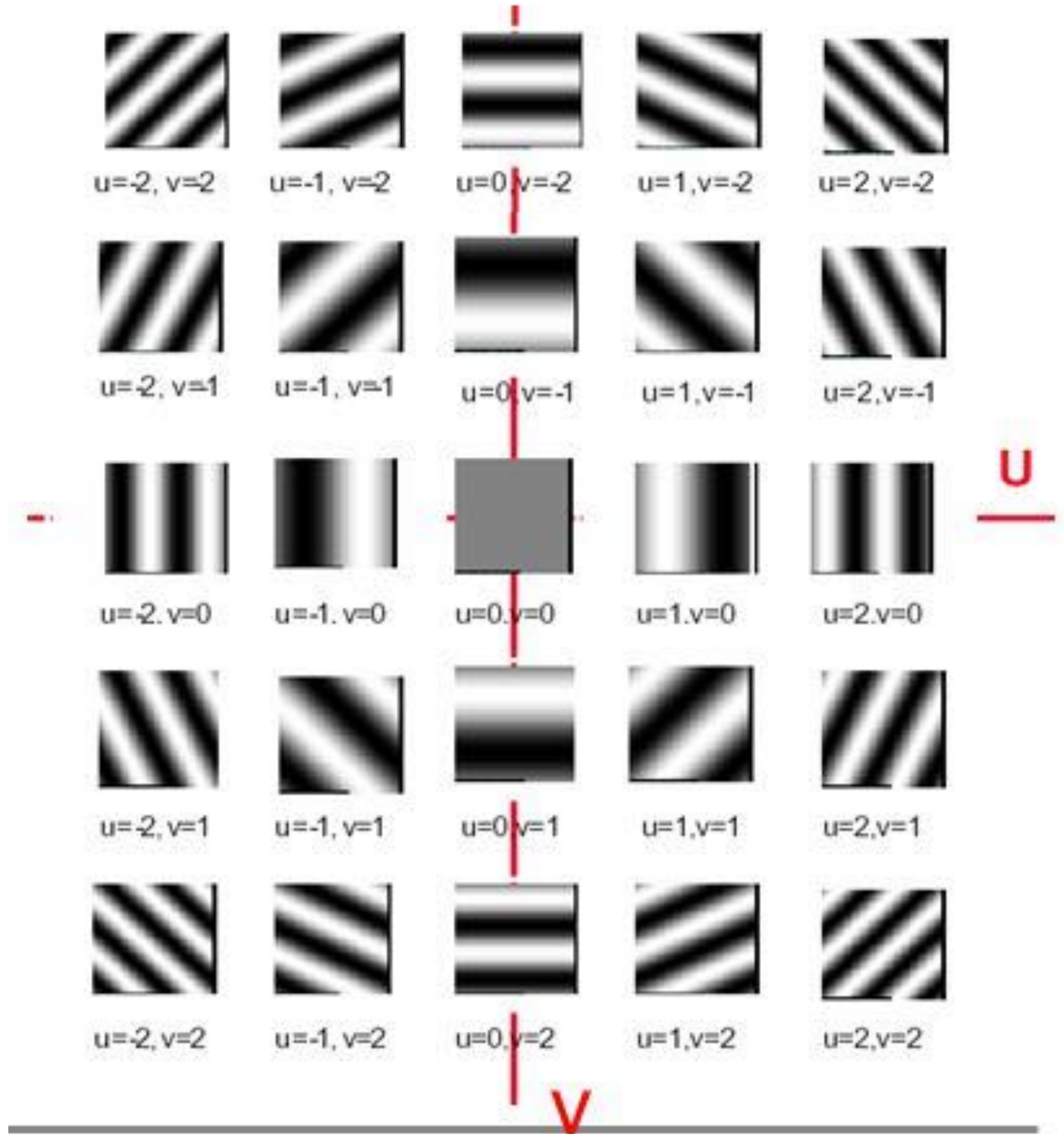
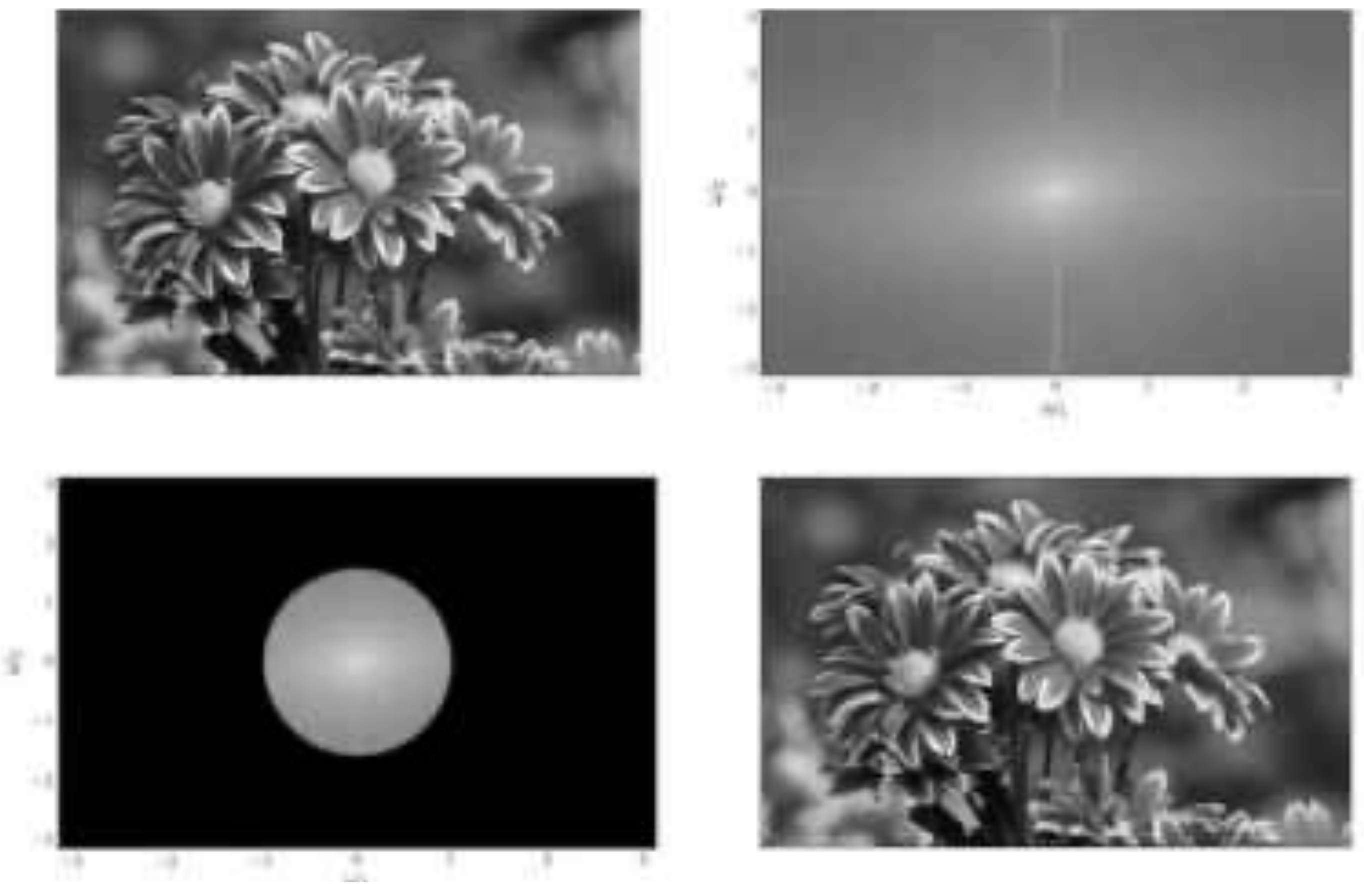


Image Spectra

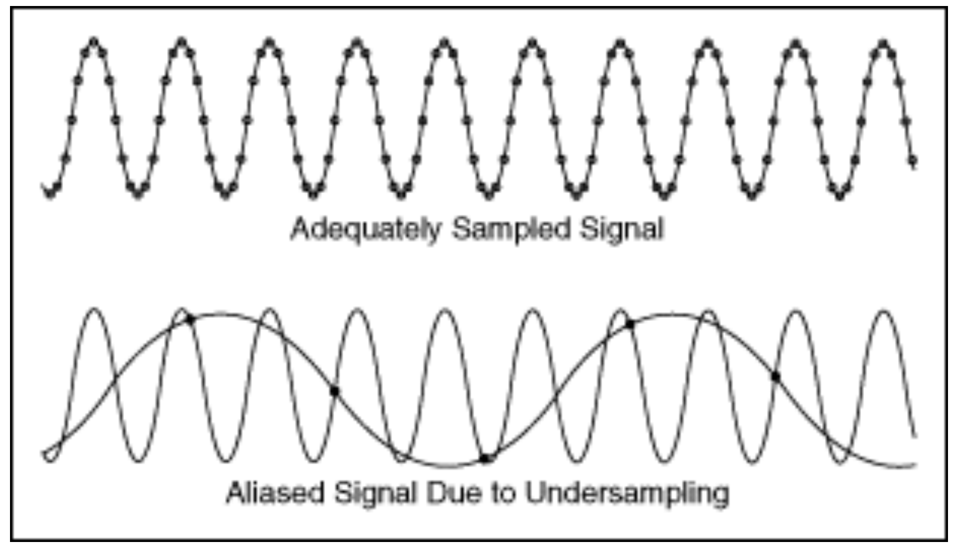


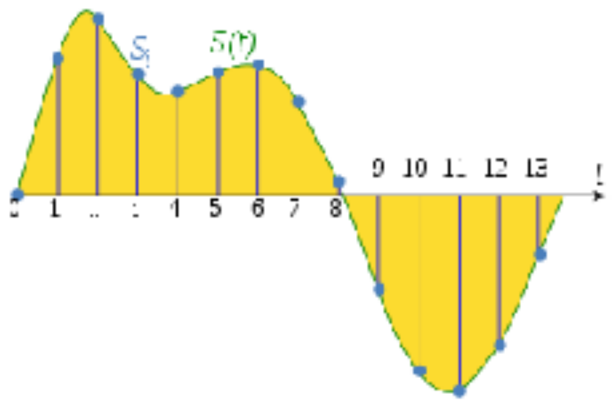
Convolution Theorem

Sampling/Blending/Image Period

Sampling/Blending/Image Period

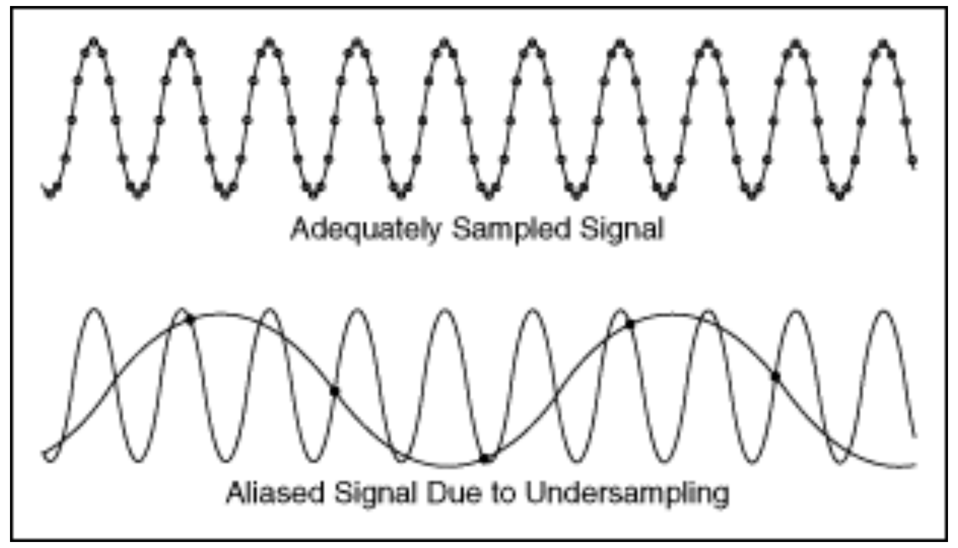
Sampling and aliasing

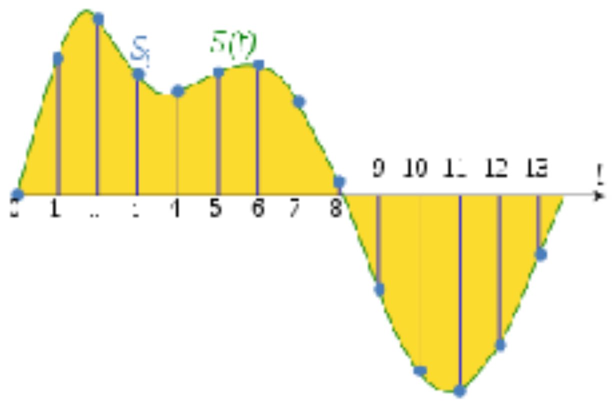




Sampling/Blending/Image Period

Sampling and aliasing

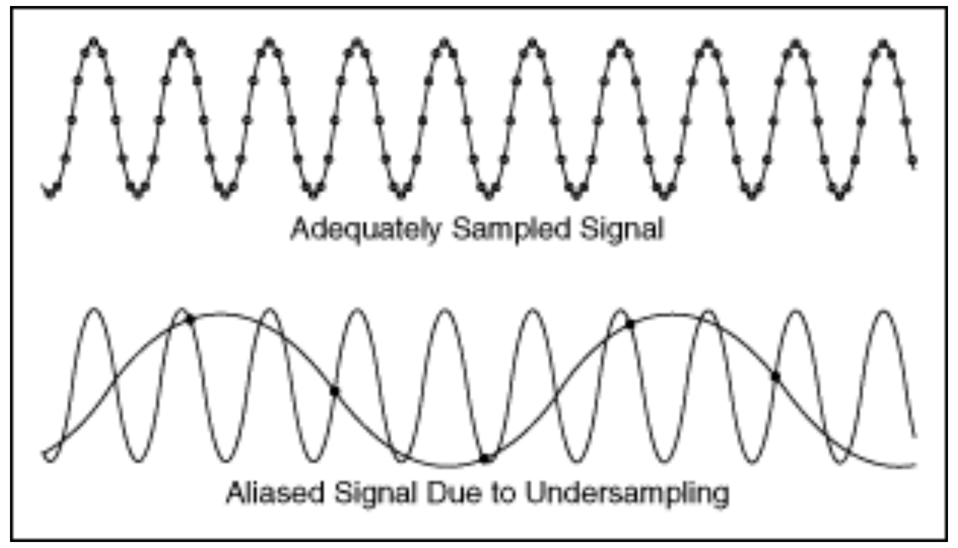


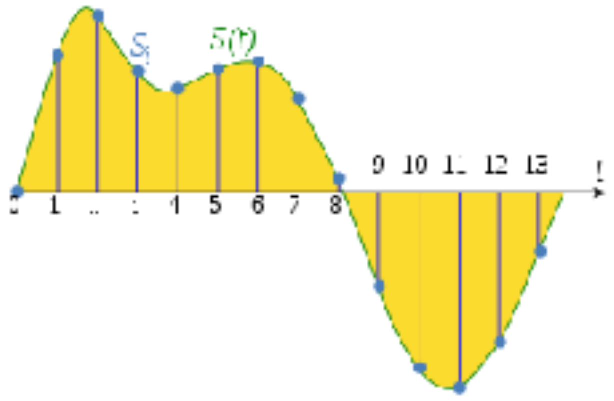


Aliasing

Sampling/Blending/Image Period

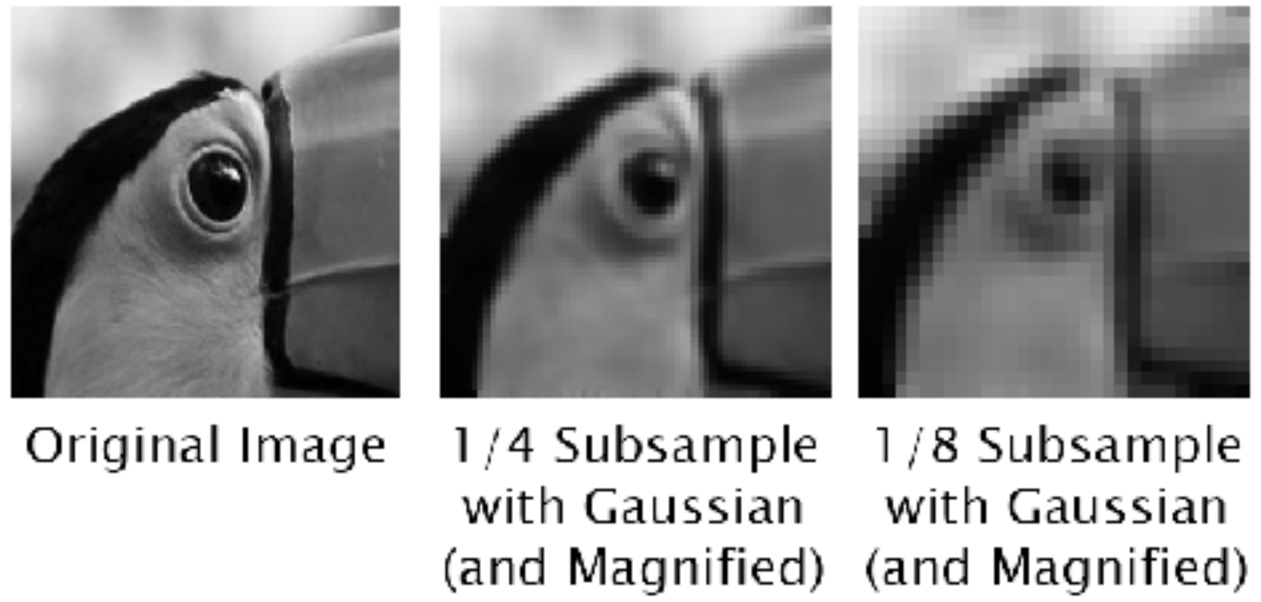
Sampling and aliasing





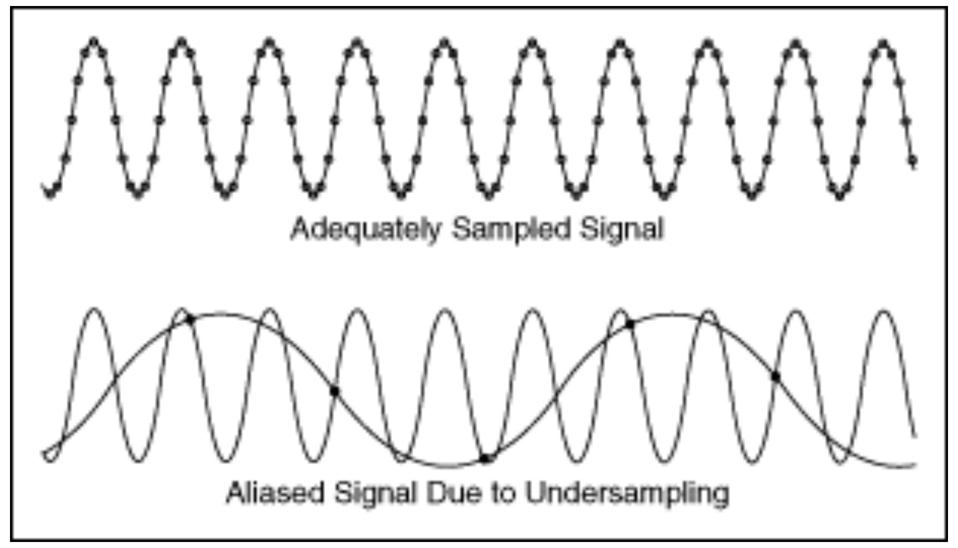
Aliasing

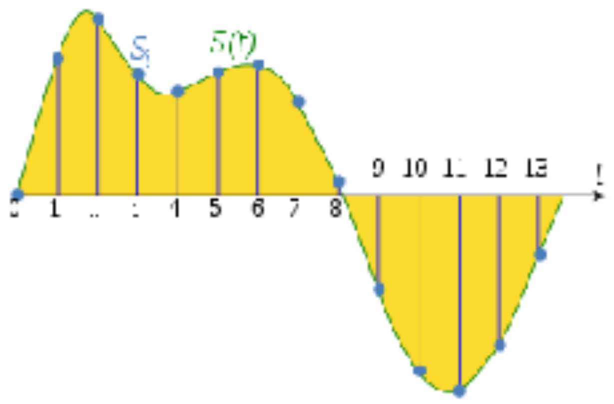
Preventing aliasing



Sampling/Blending/Image Period

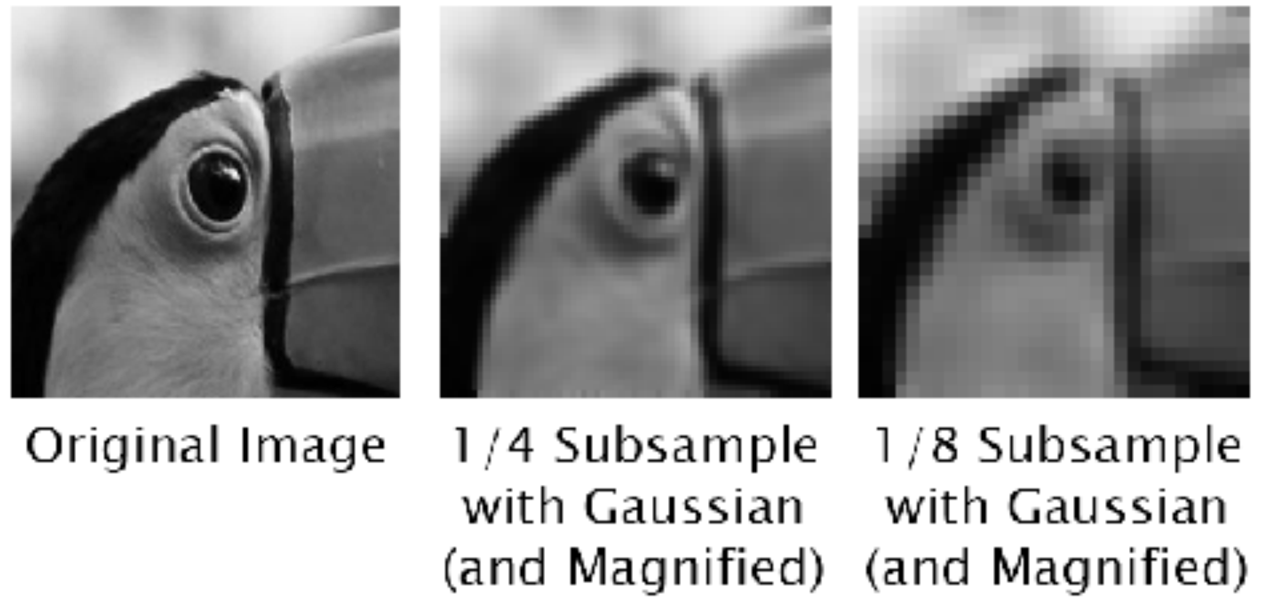
Sampling and aliasing



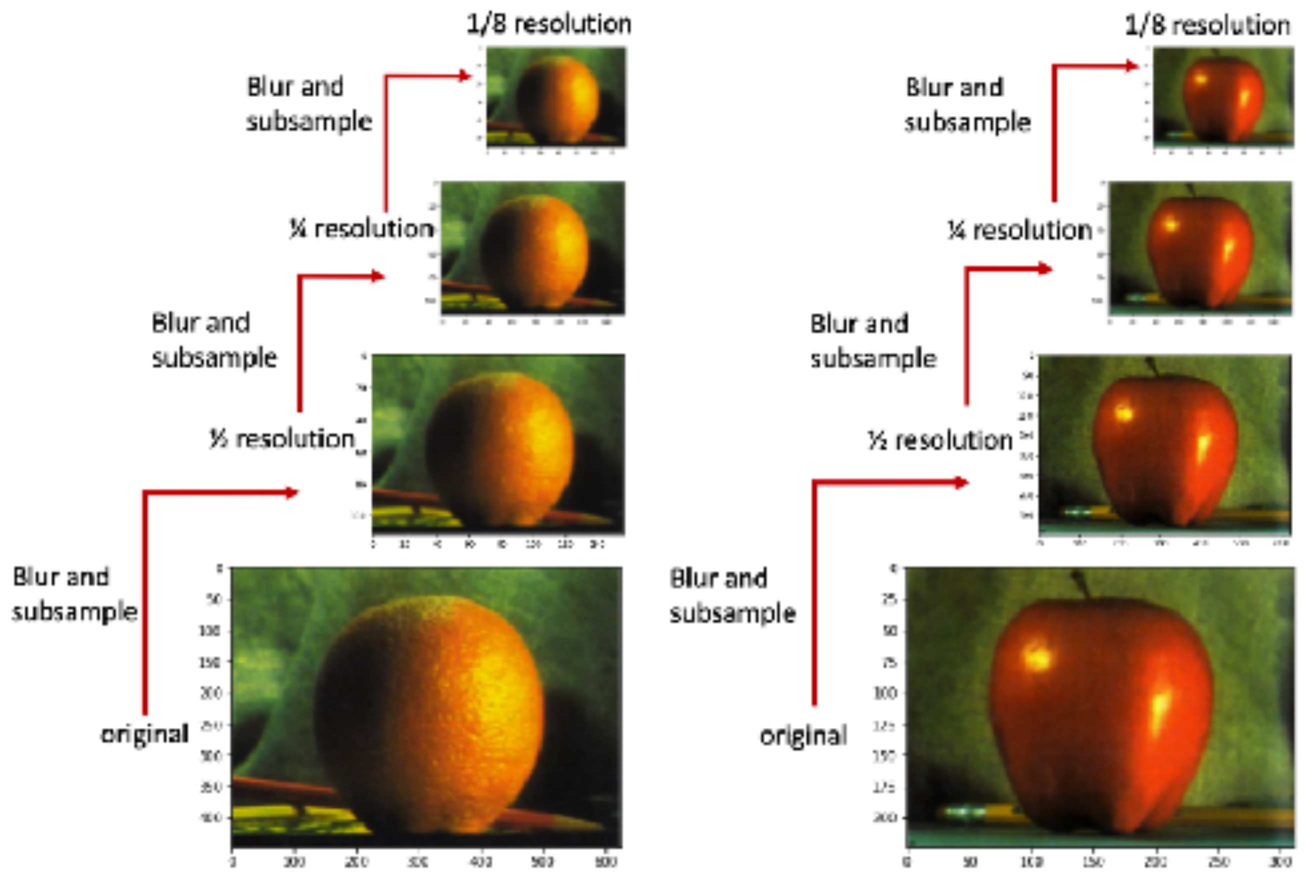


Aliasing

Preventing aliasing

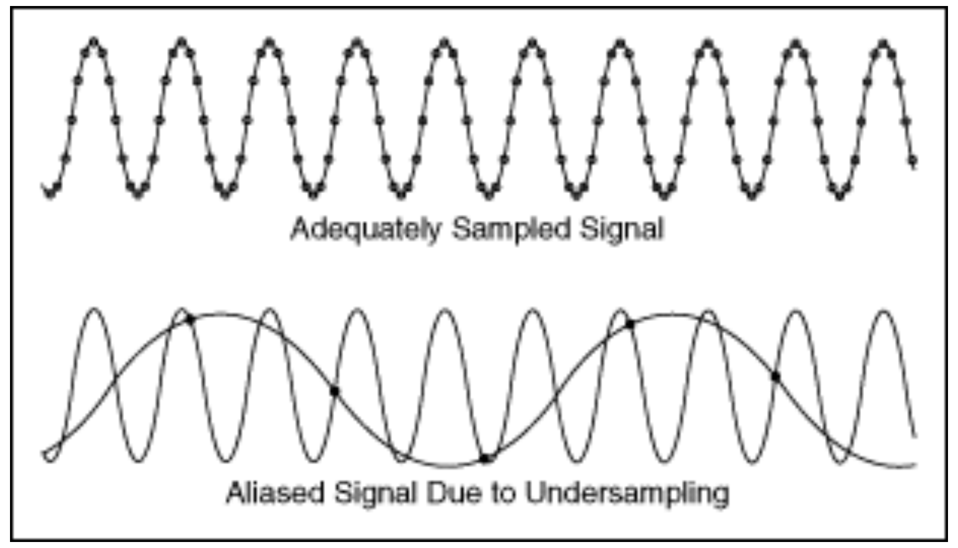


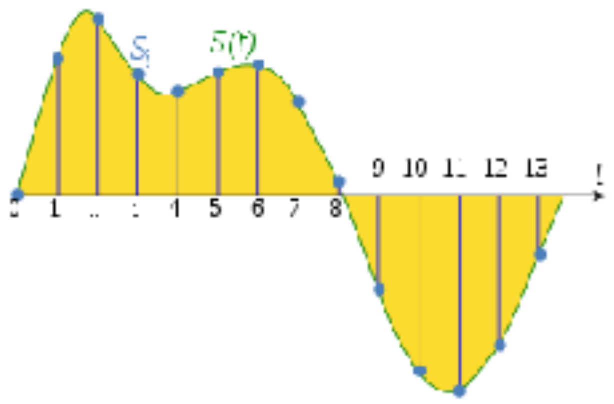
Gaussian pyramids



Sampling/Blending/Image Period

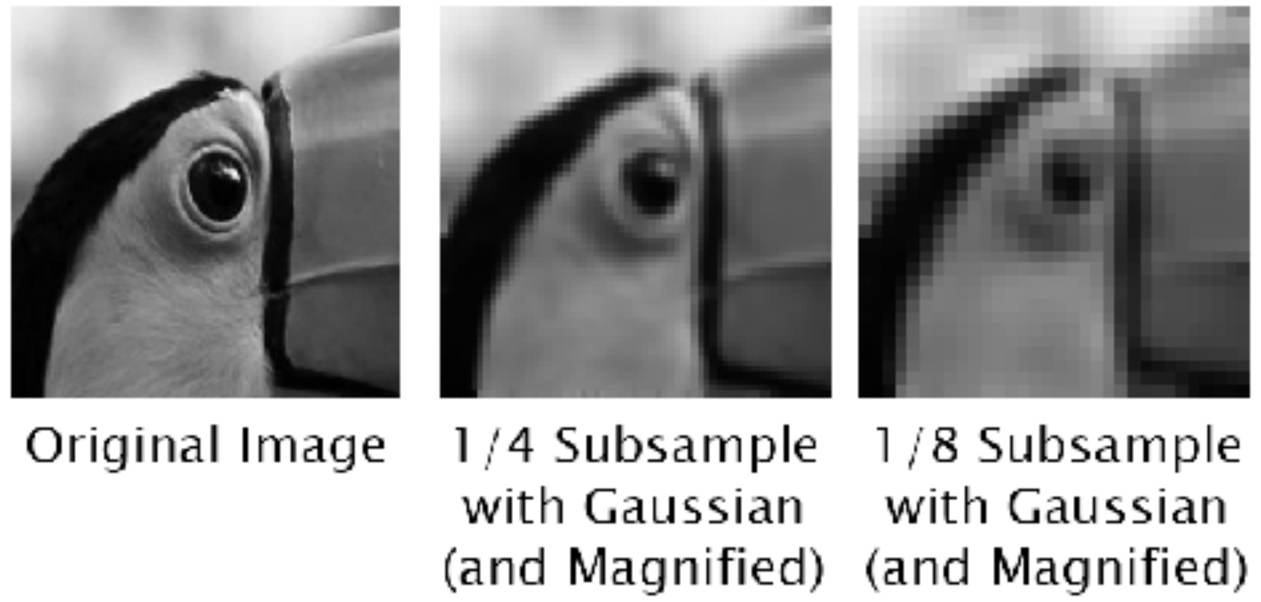
Sampling and aliasing



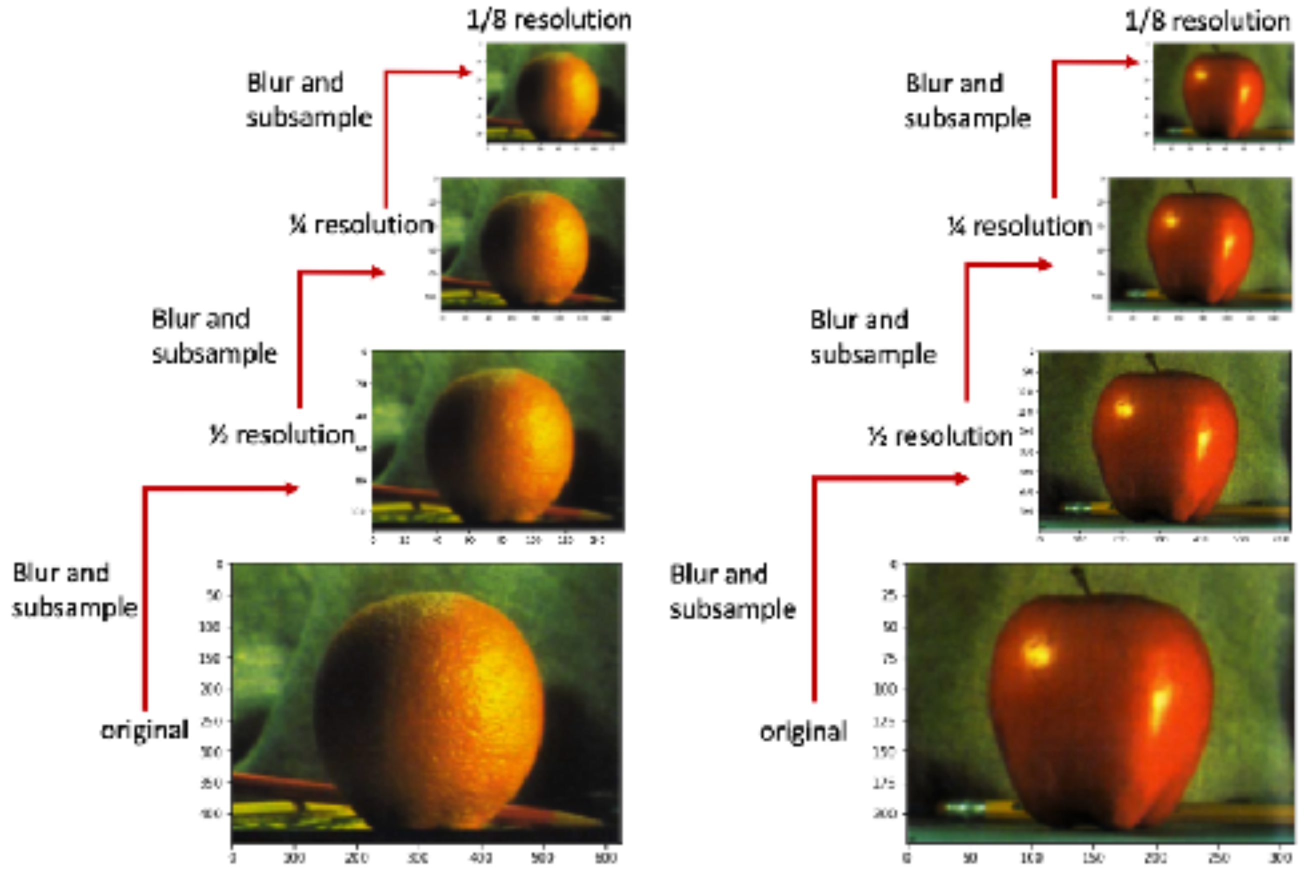


Aliasing

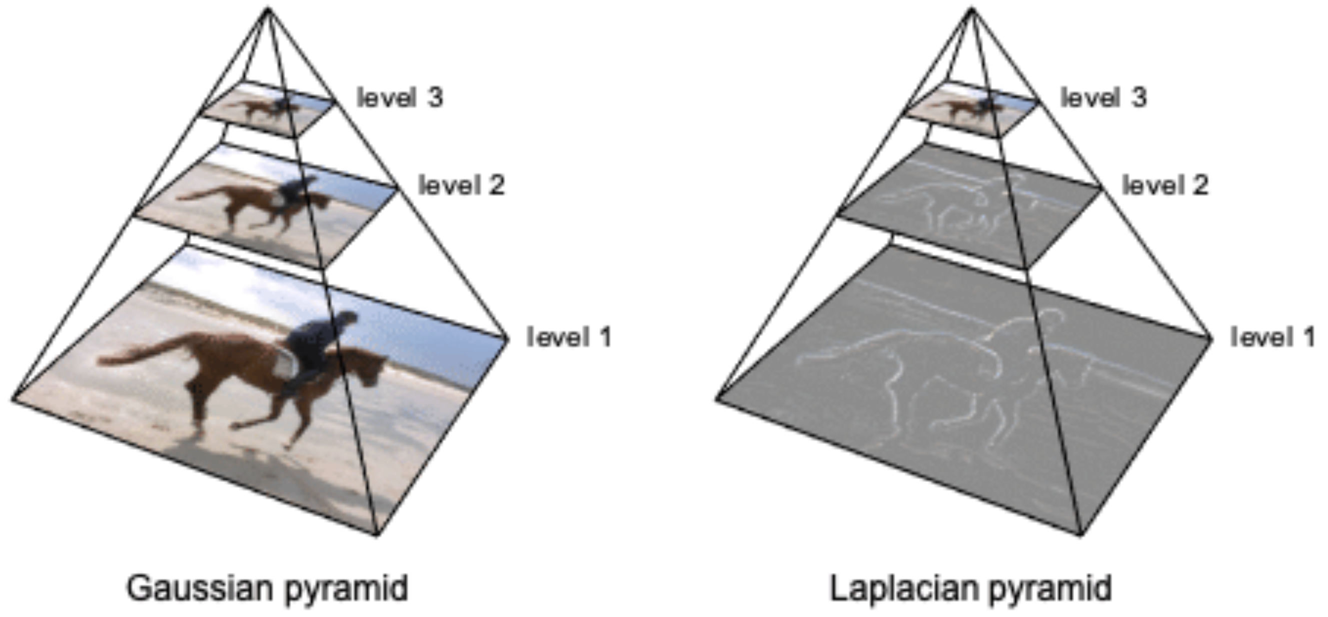
Preventing aliasing



Gaussian pyramids

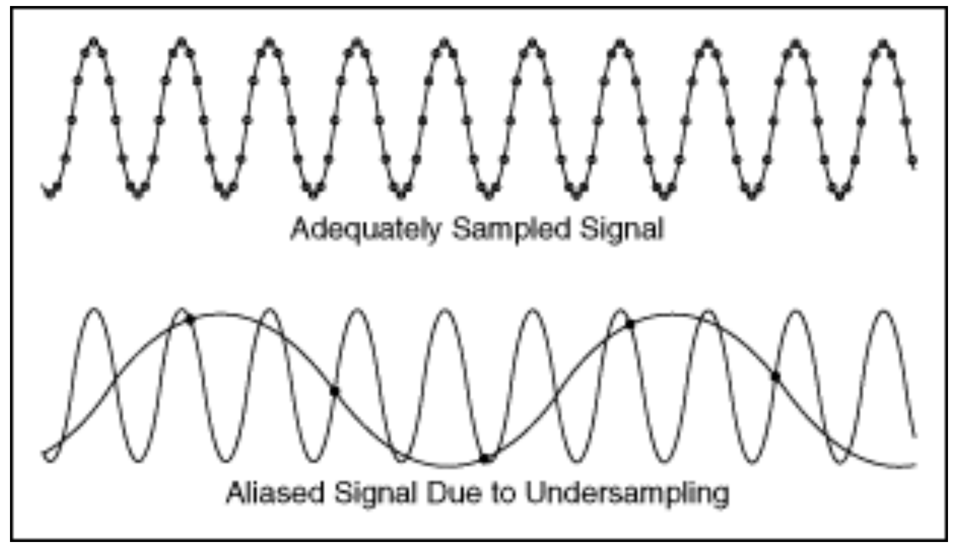


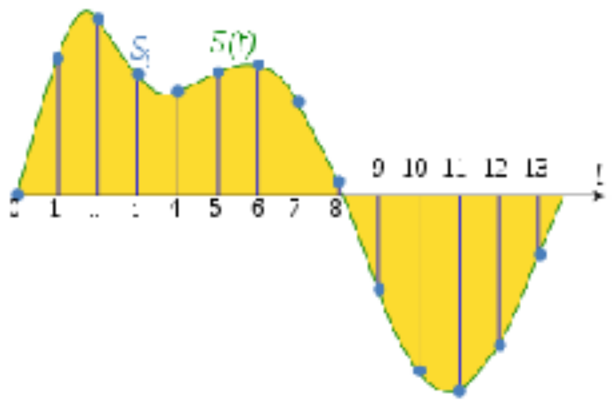
Laplacian pyramids



Sampling/Blending/Image Period

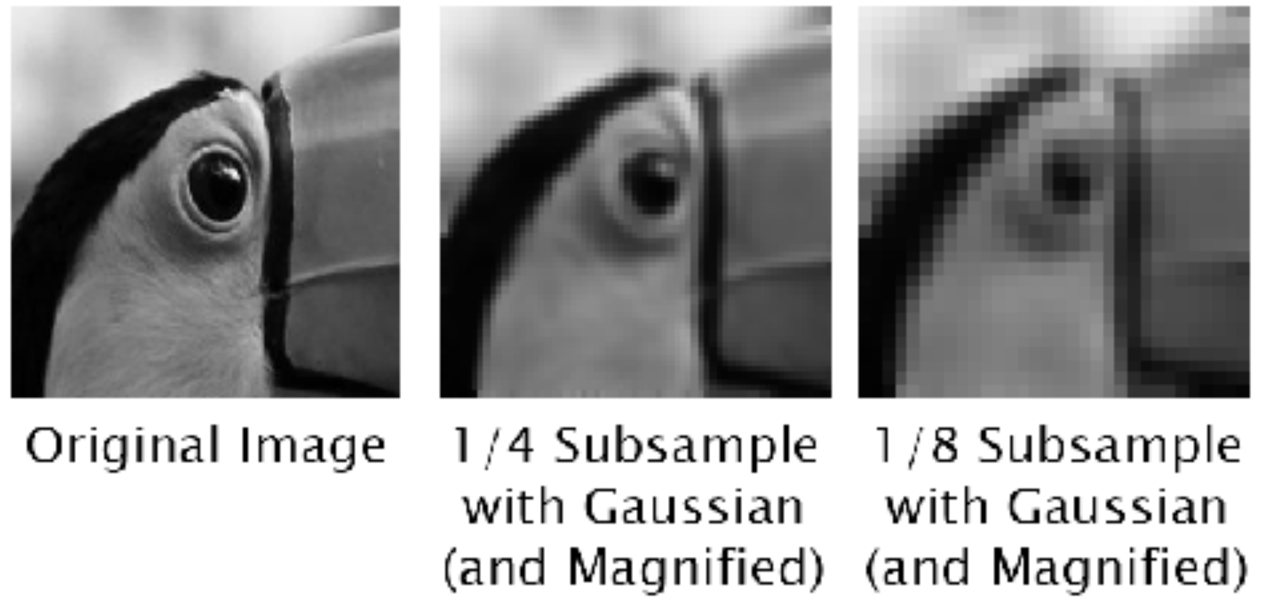
Sampling and aliasing



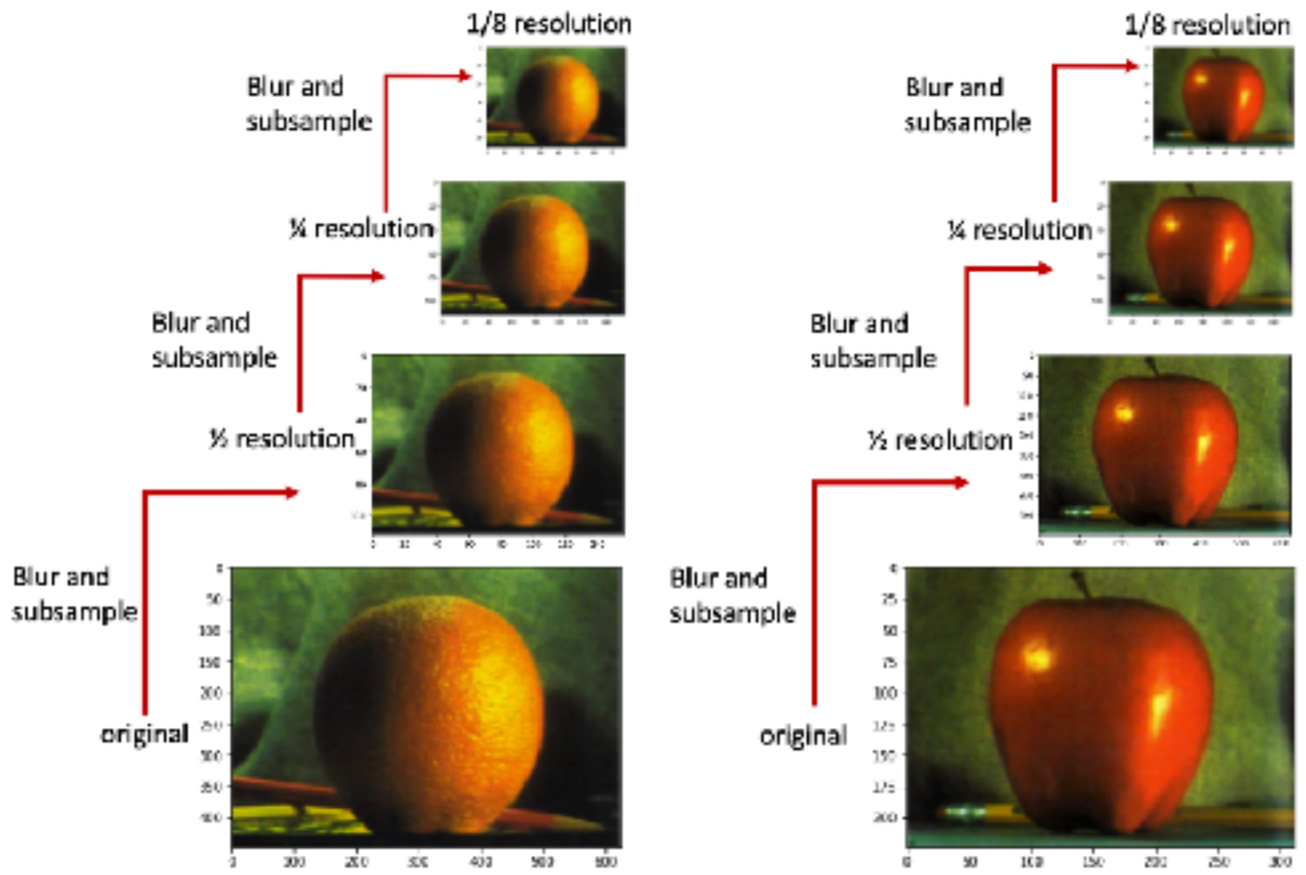


Aliasing

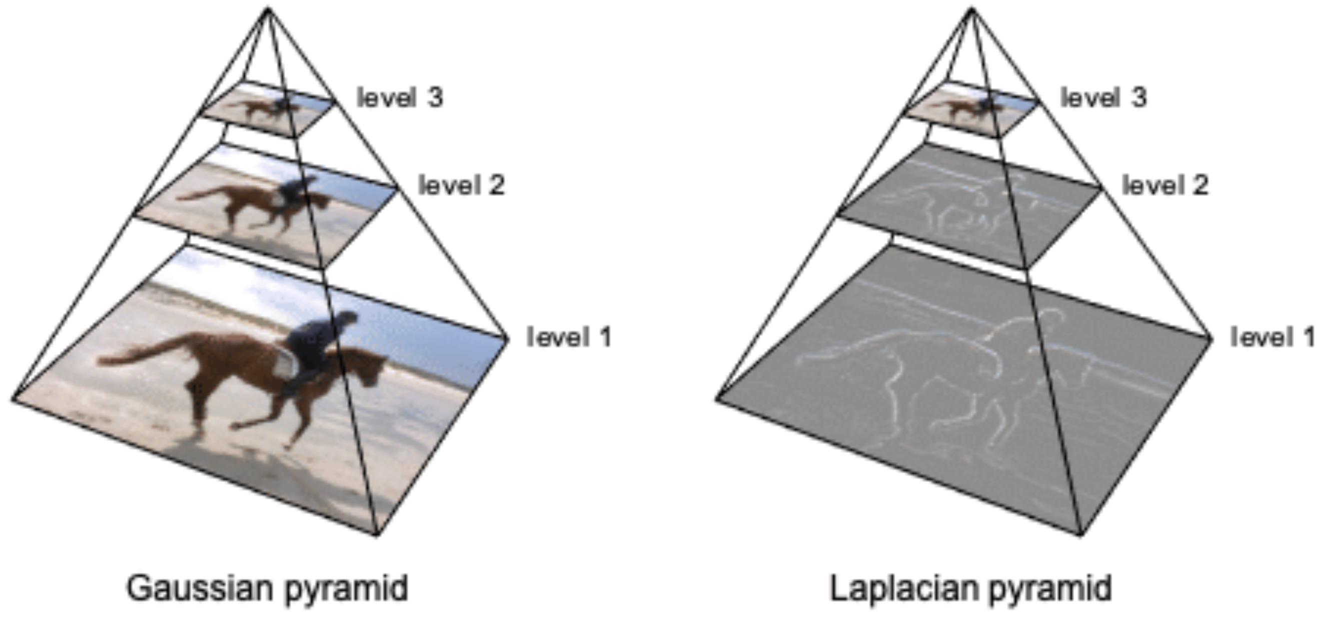
Preventing aliasing



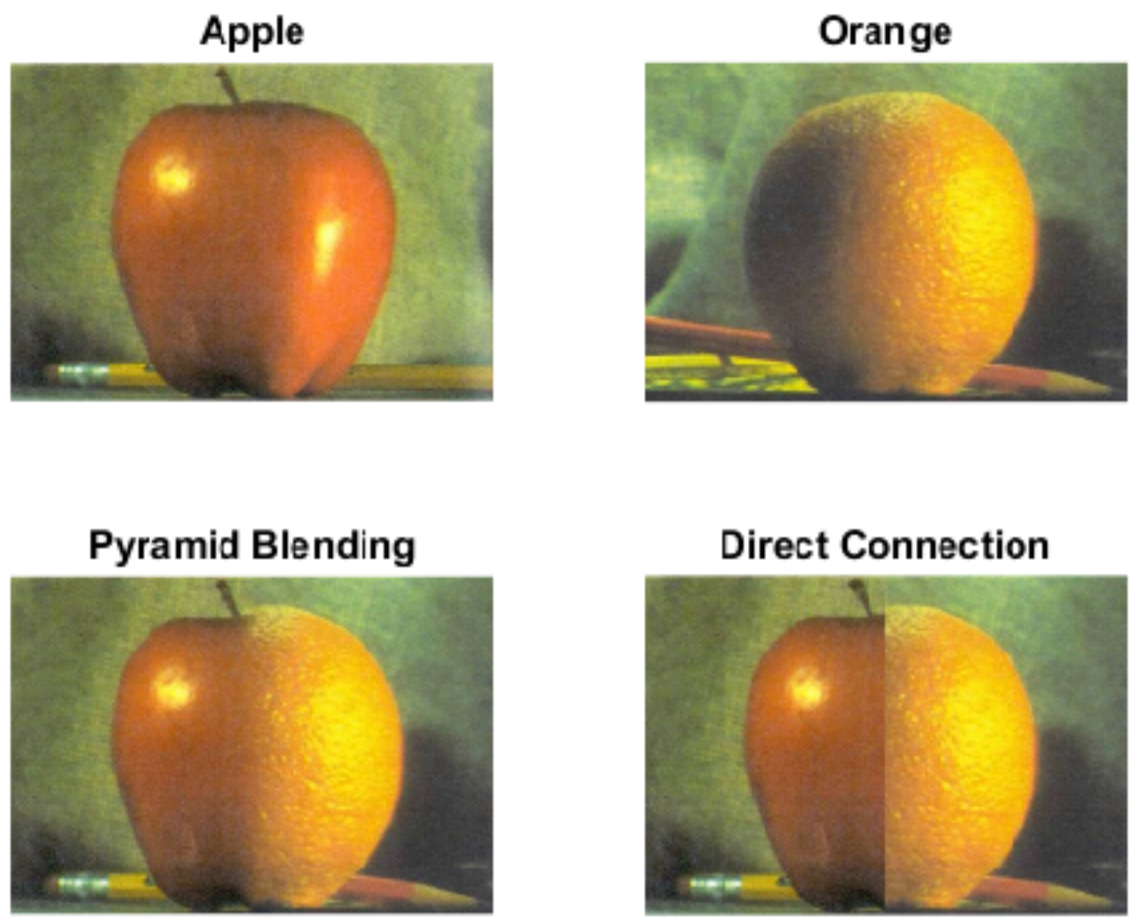
Gaussian pyramids



Laplacian pyramids



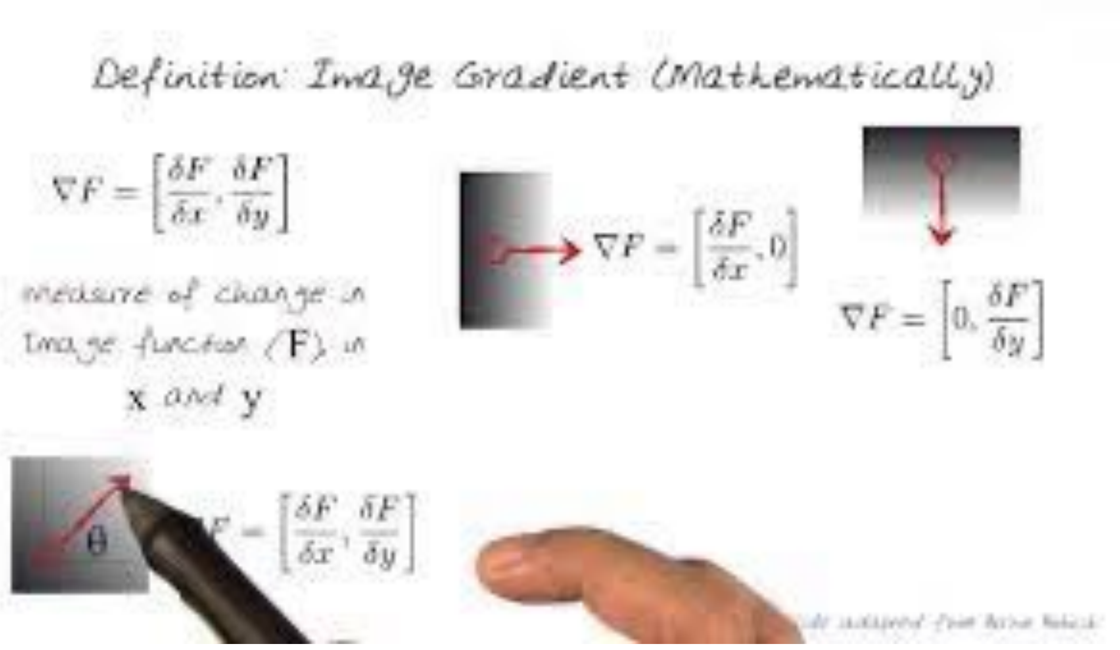
Blending



Edge Detectors

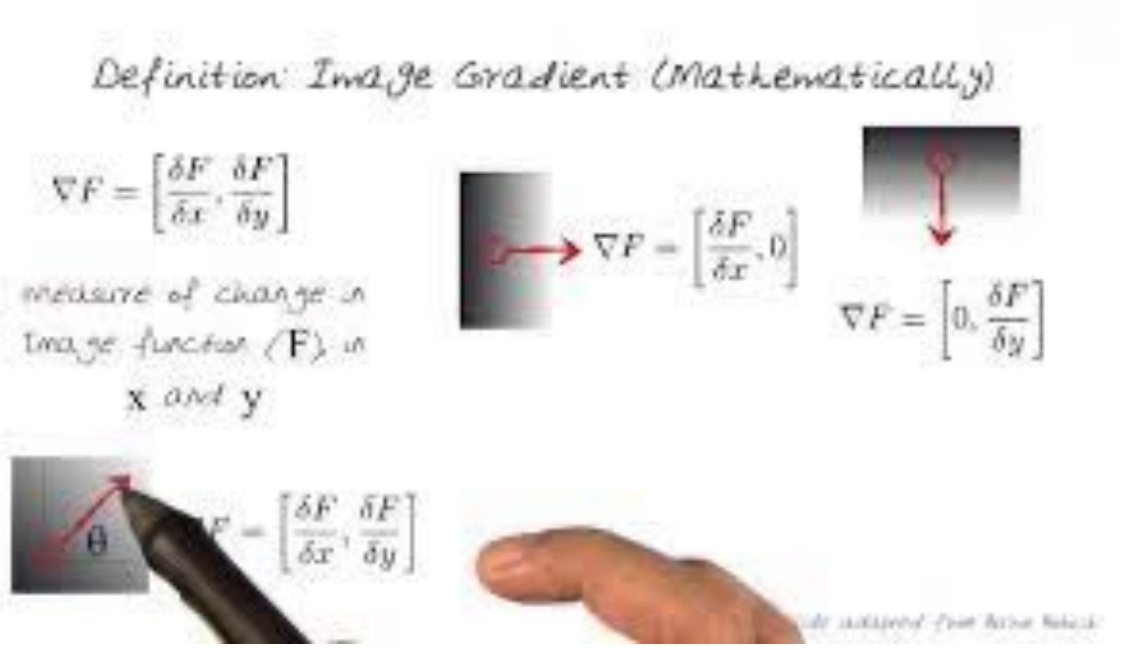
Edge Detectors

Image gradients



Edge Detectors

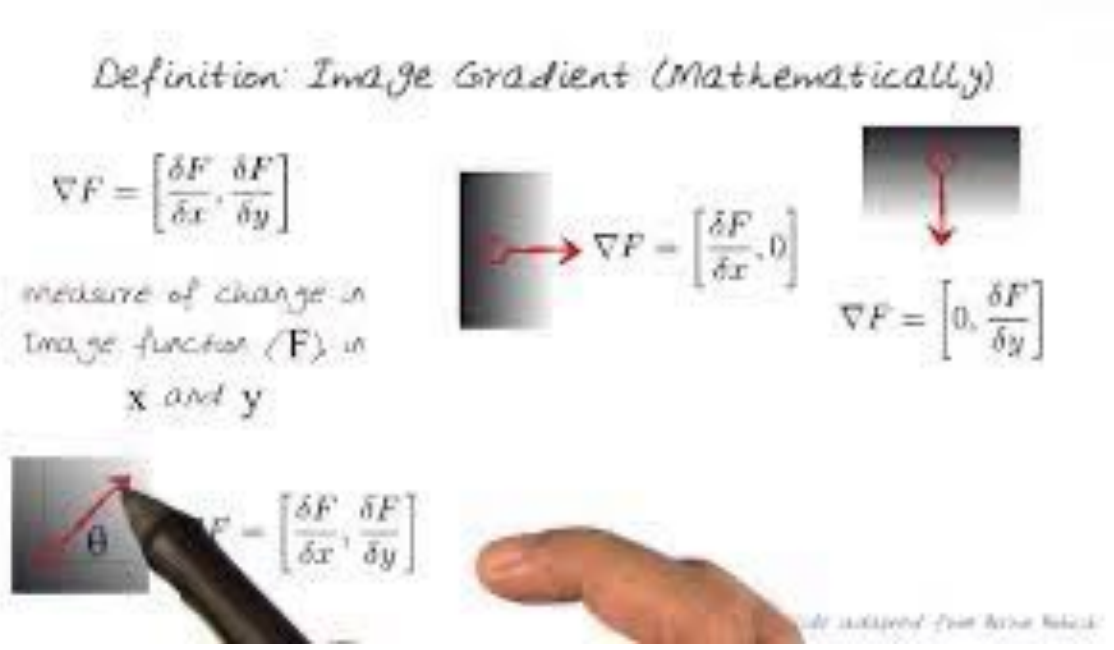
Image gradients



Edge maps

Edge Detectors

Image gradients



Edge maps

Canny edge detector

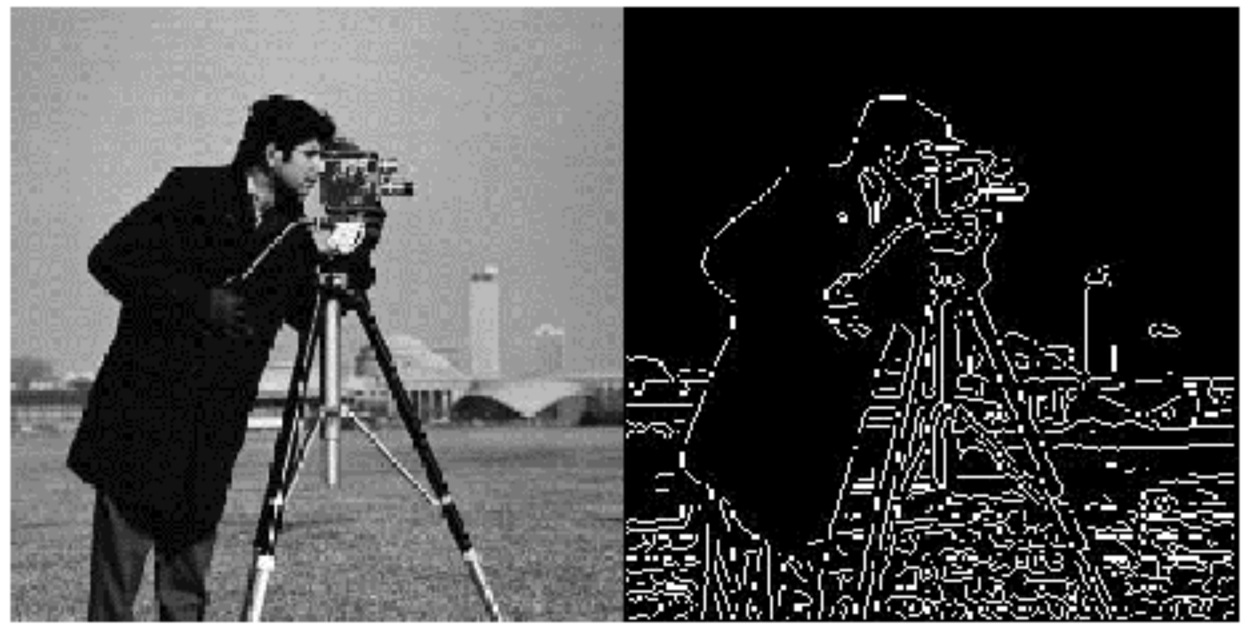
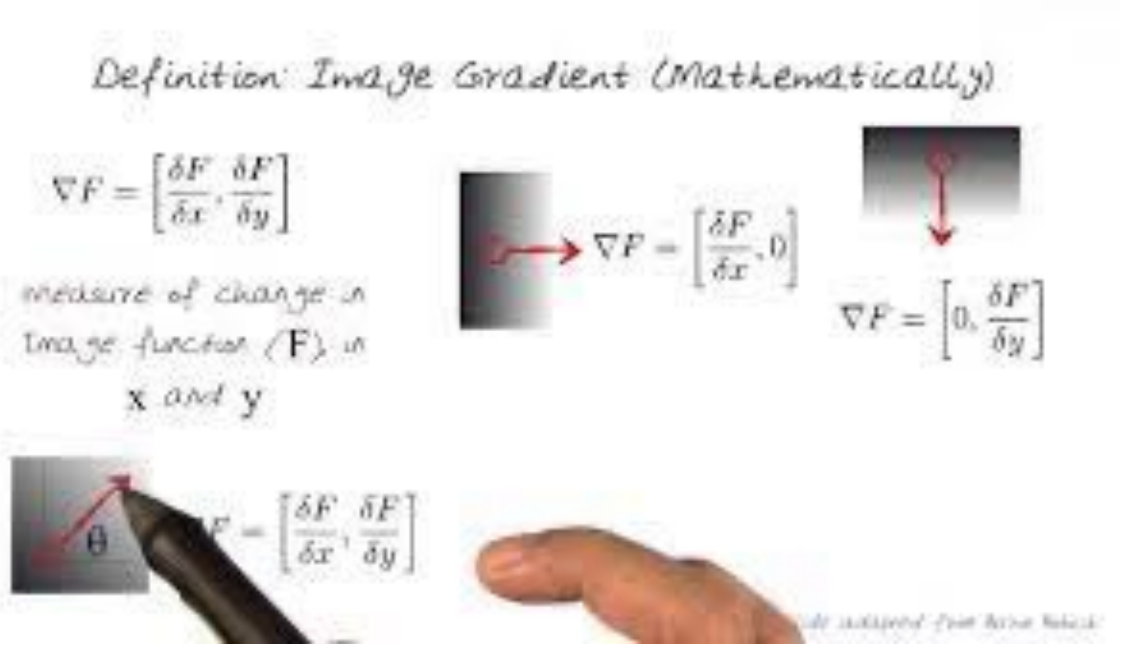


Figure 1: The cameraman image and its edges extracted

Edge Detectors

Image gradients



Edge maps

Canny edge detector

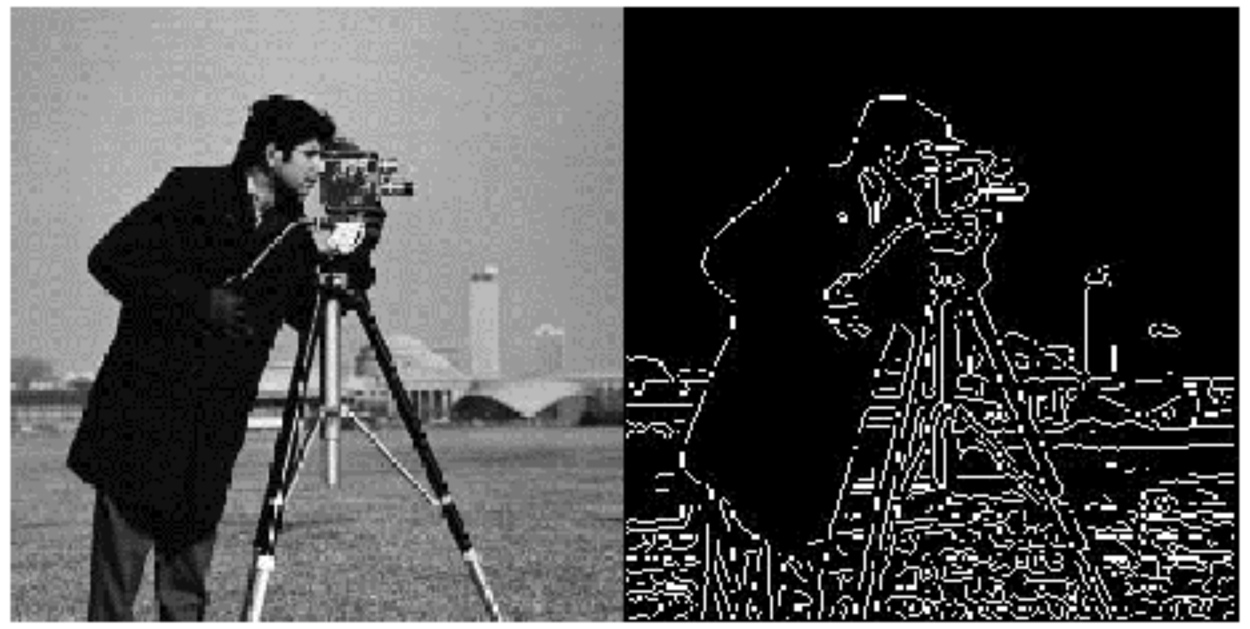
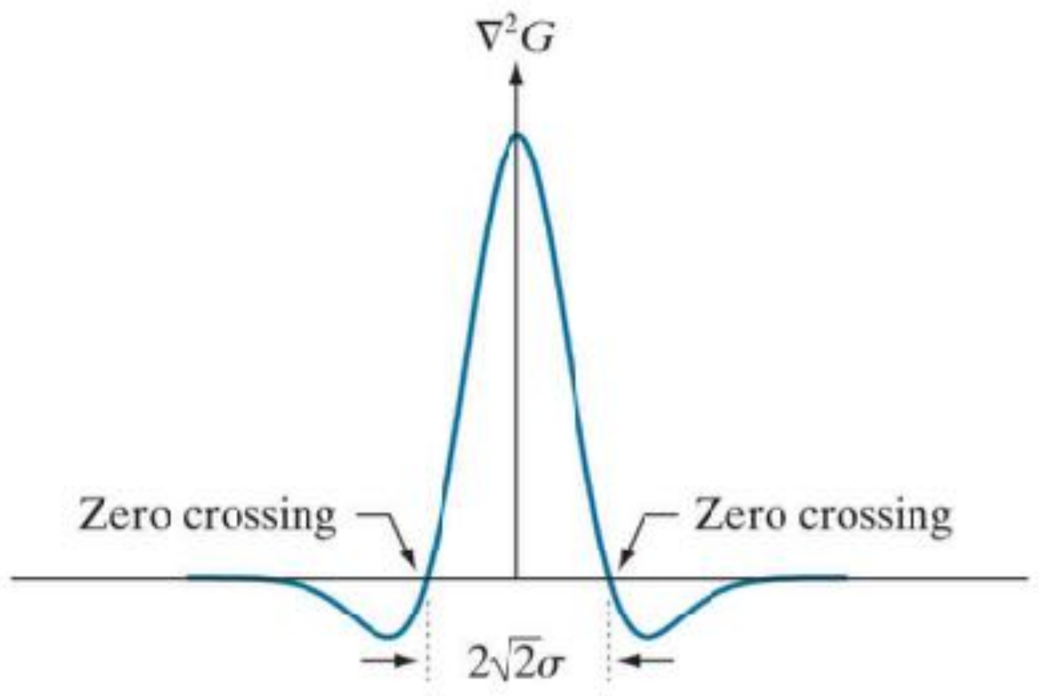


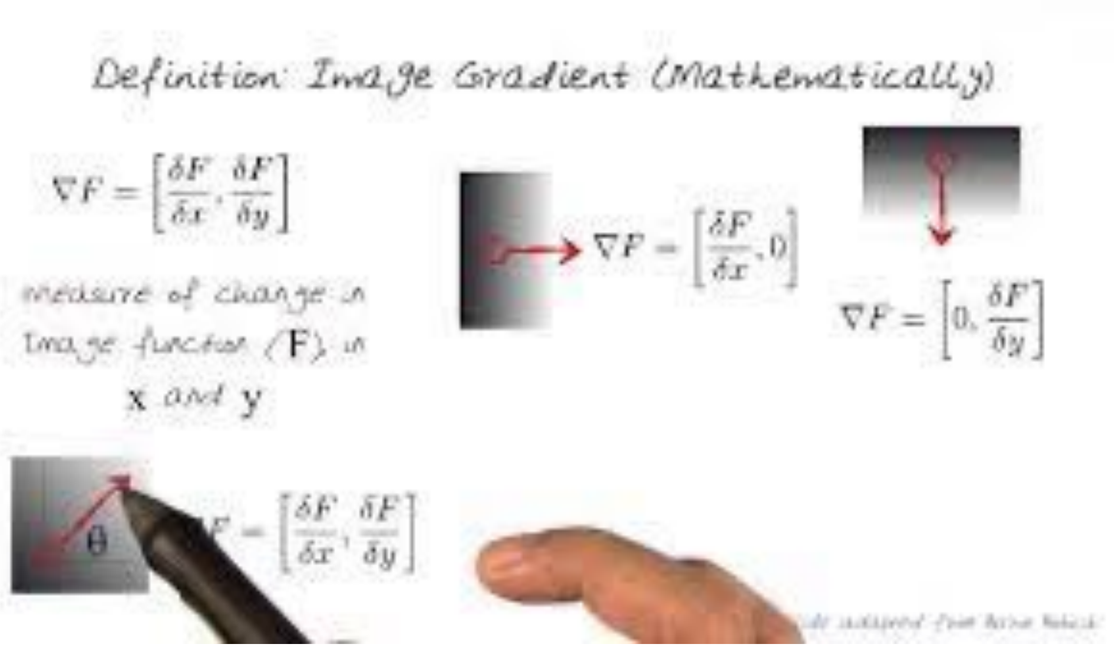
Figure 1: The cameraman image and its edges extracted

Laplacian/ DOG



Edge Detectors

Image gradients



Edge maps

Canny edge detector

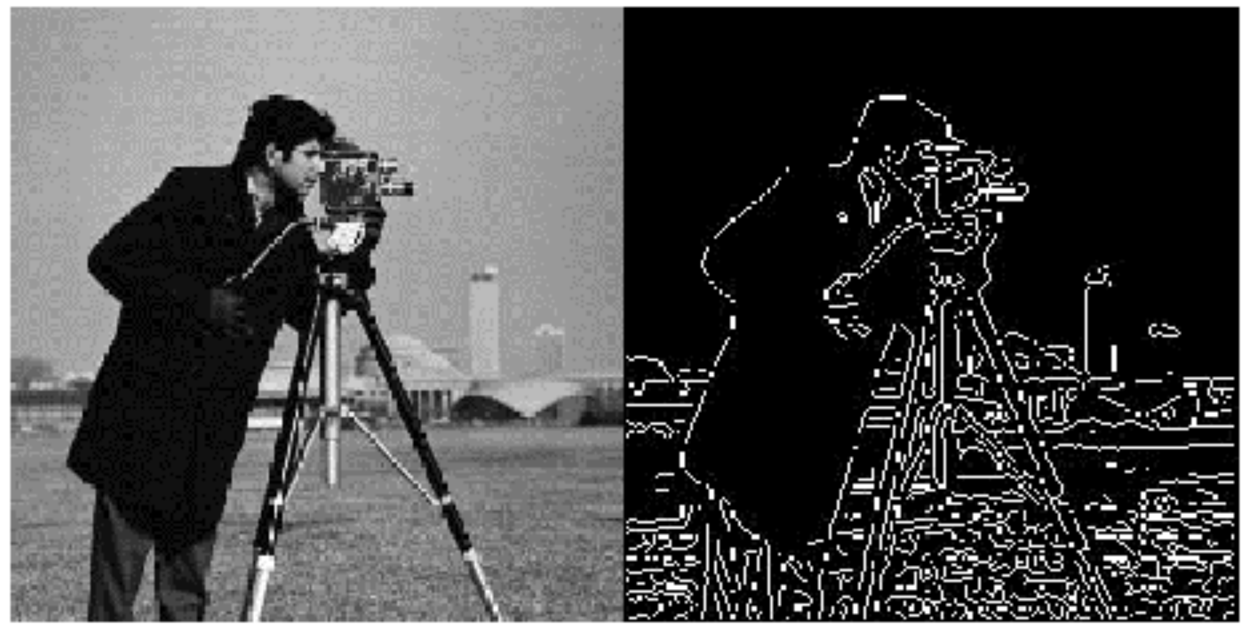
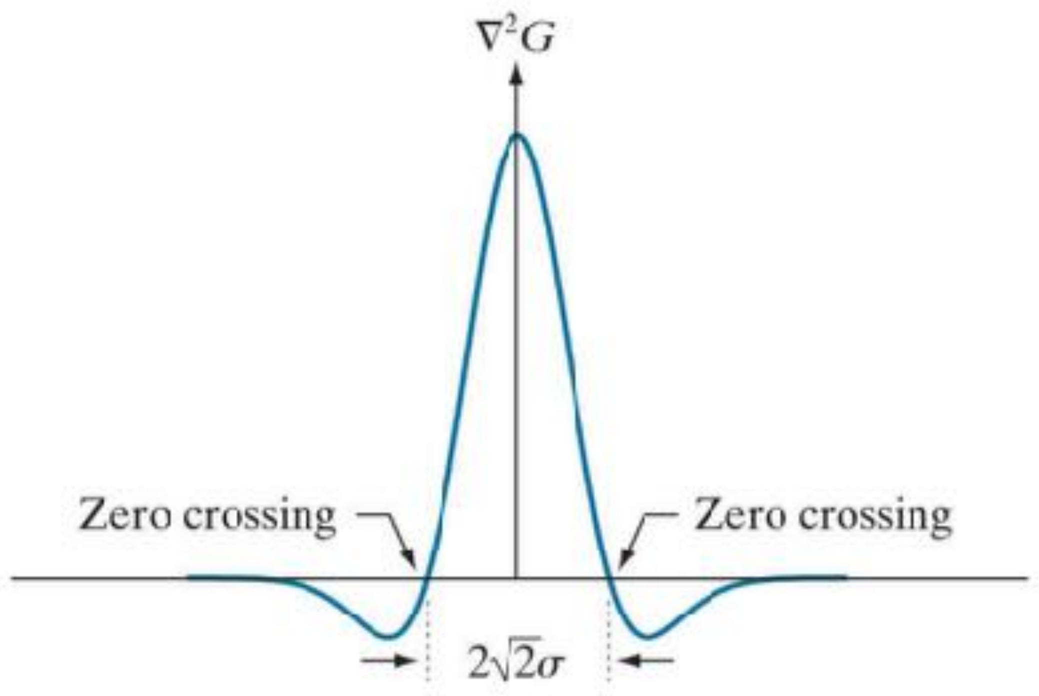


Figure 1: The cameraman image and its edges extracted

Laplacian/ DOG



Laplacian zero crossings

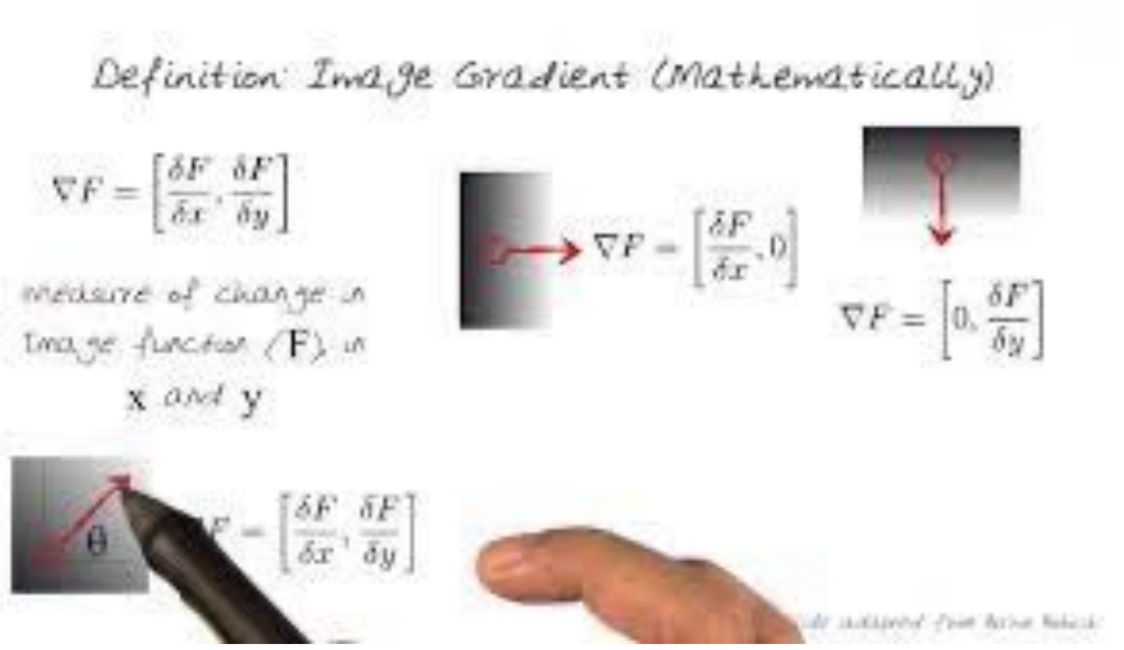
(A) Original MR image

(B) Laplacian results

(C) Extraction of the zero crossing of the Laplacian (object edges)

Edge Detectors

Image gradients



Edge maps

Canny edge detector

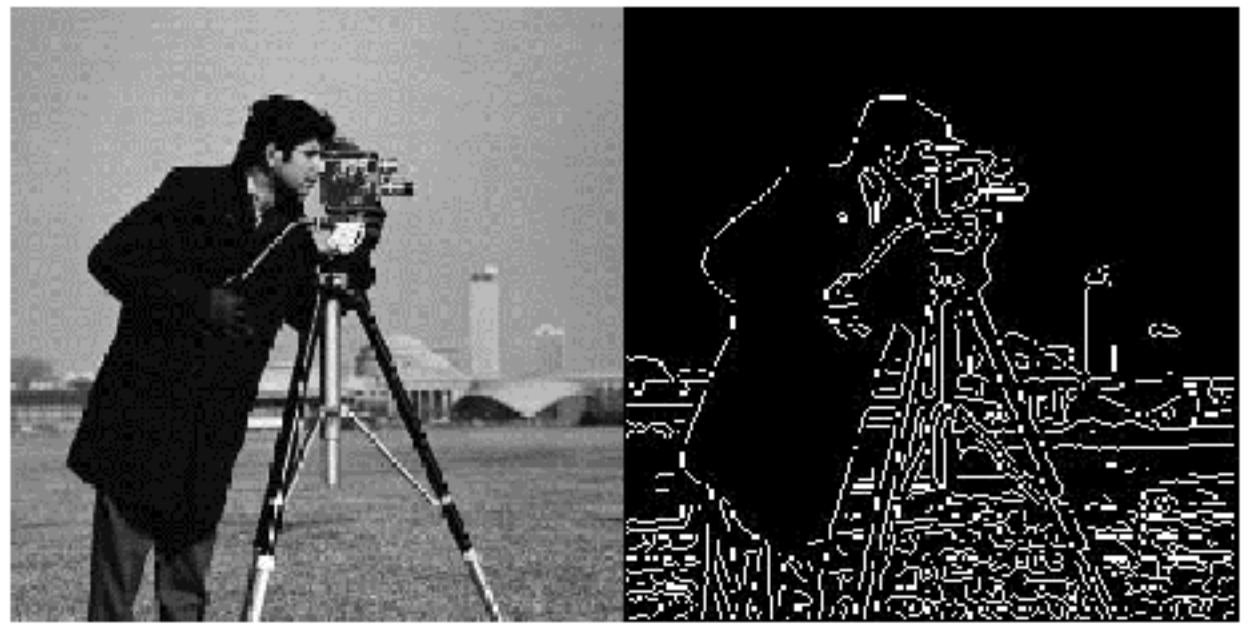
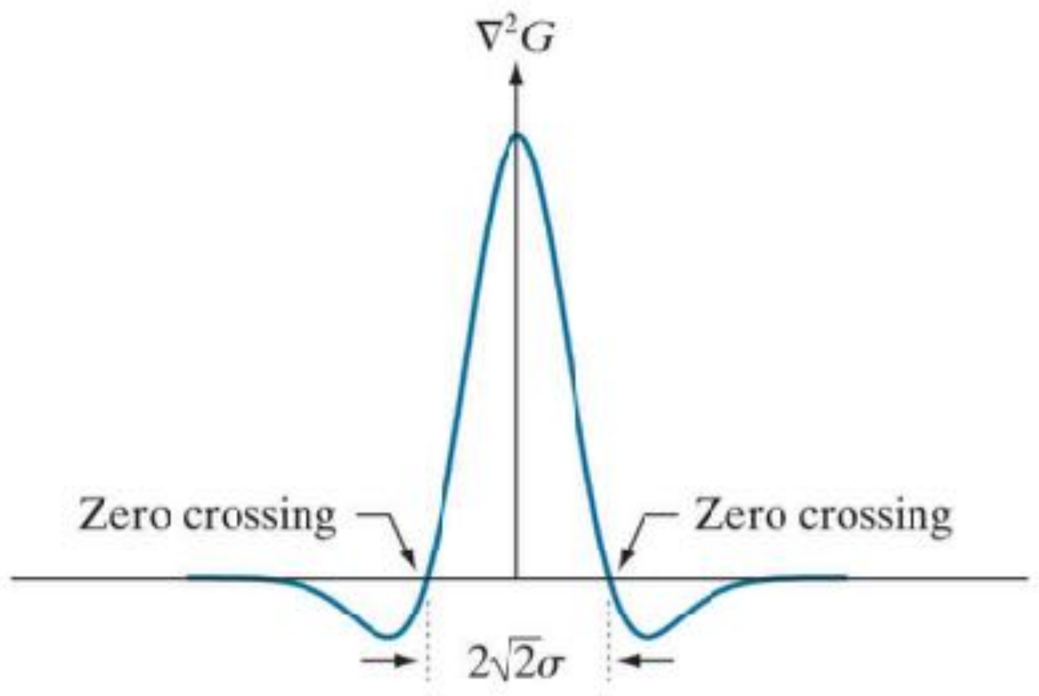


Figure 1: The cameraman image and its edges extracted

Laplacian/ DOG



Laplacian zero crossings

(A) Original MR image

(B) Laplacian results

(C) Extraction of the zero crossing of the Laplacian (object edges)

Hough transform

Corner Detector and Features

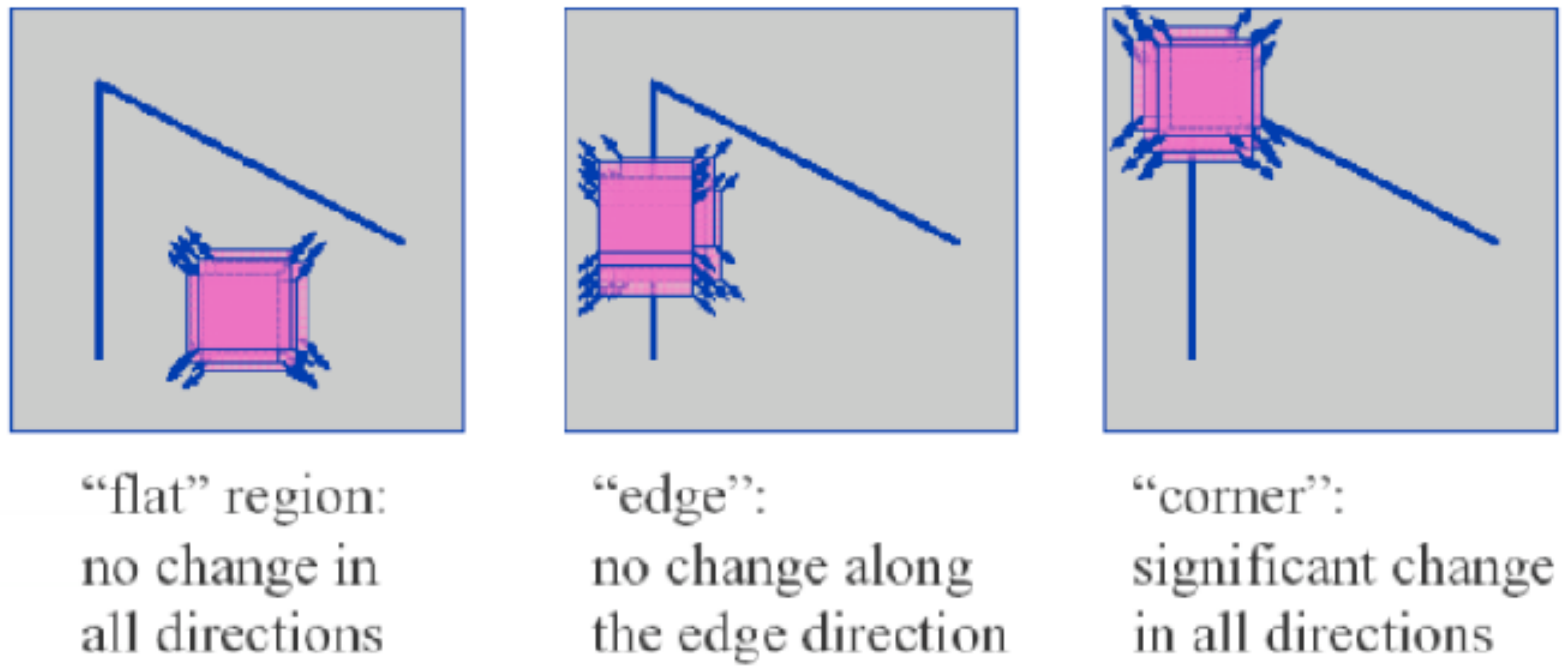
Corner Detector and Features

What are corners?

Corner Detector and Features

What are corners?

Auto-correlation



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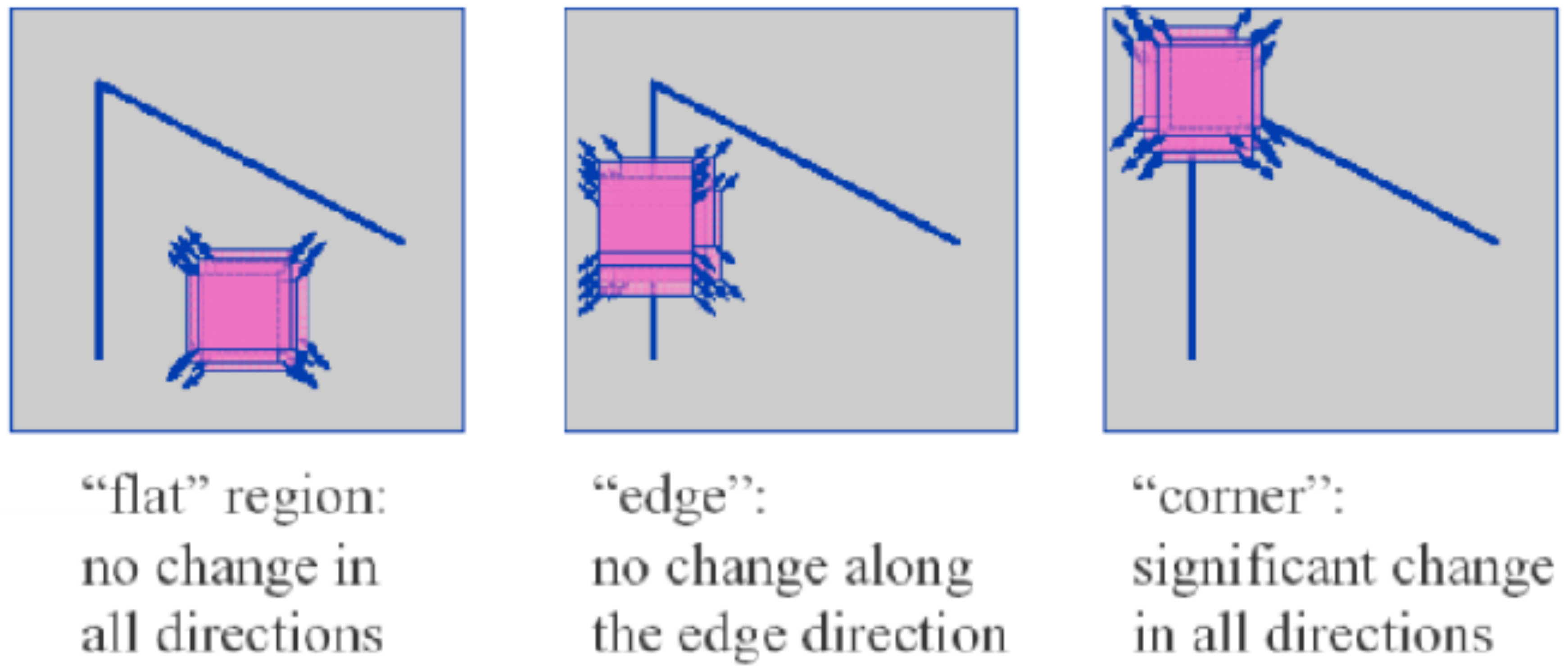
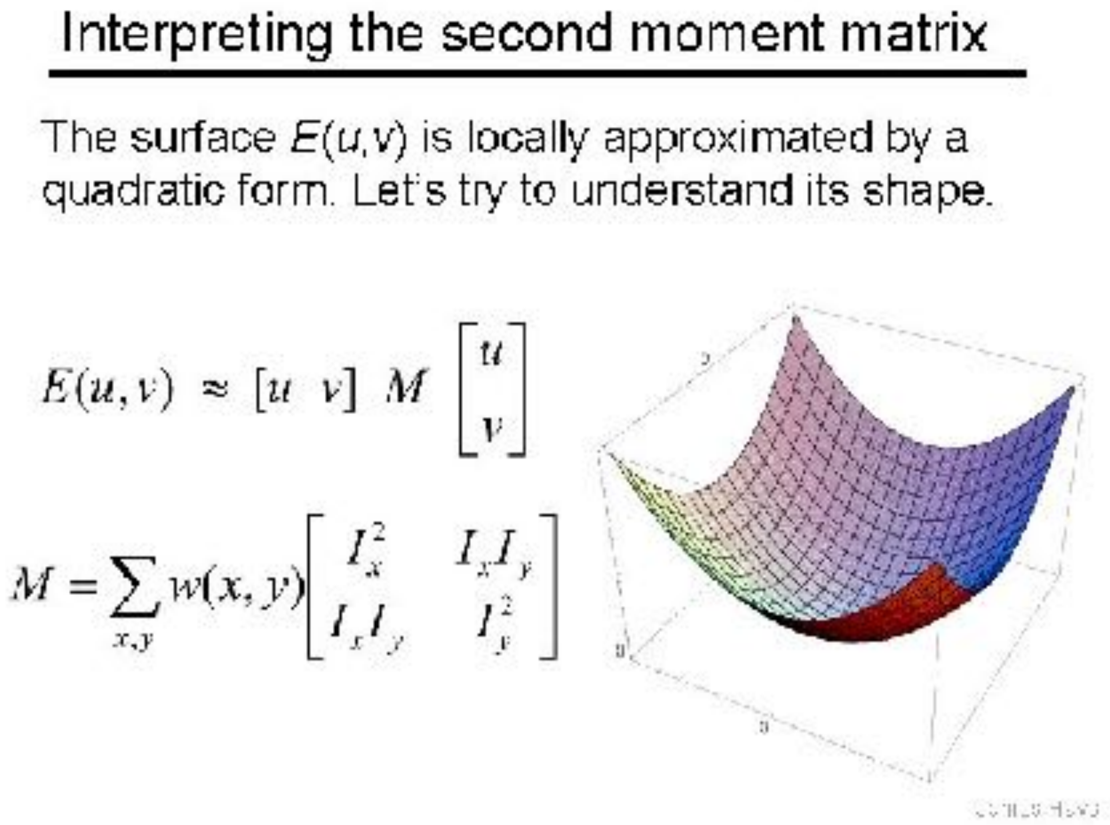


Harris Corner Detector



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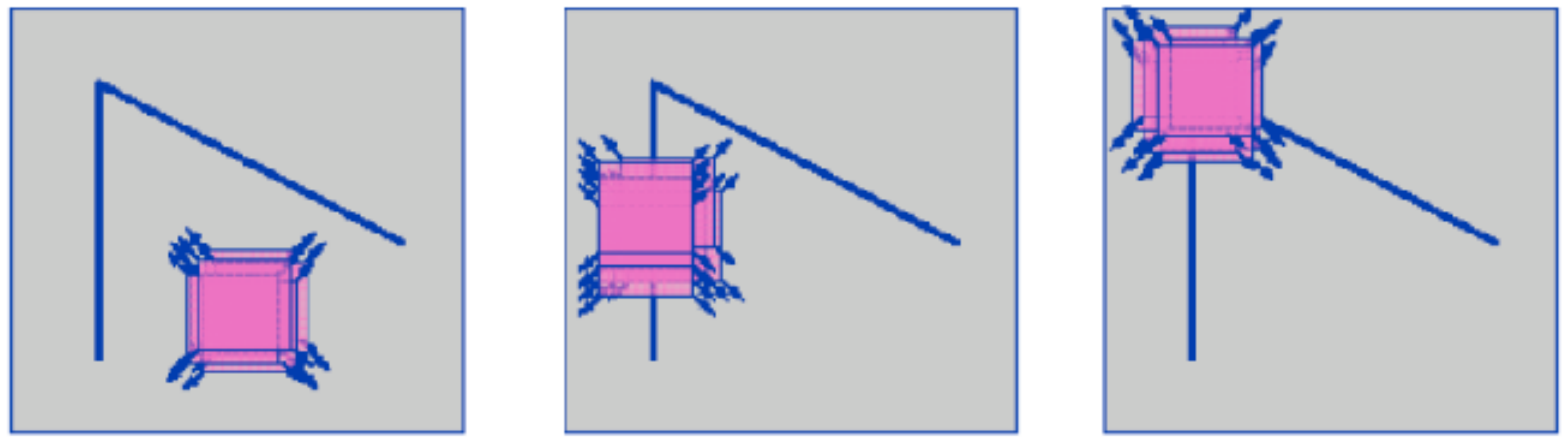
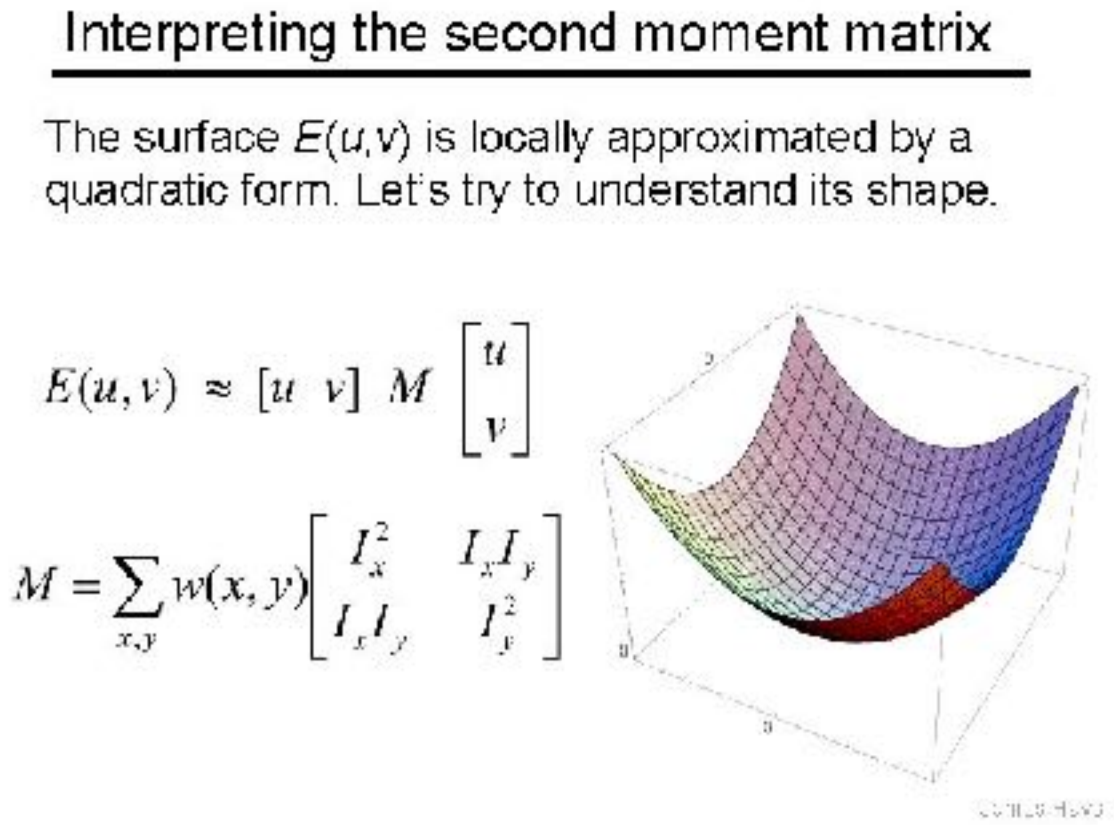


"flat" region: no change in all directions

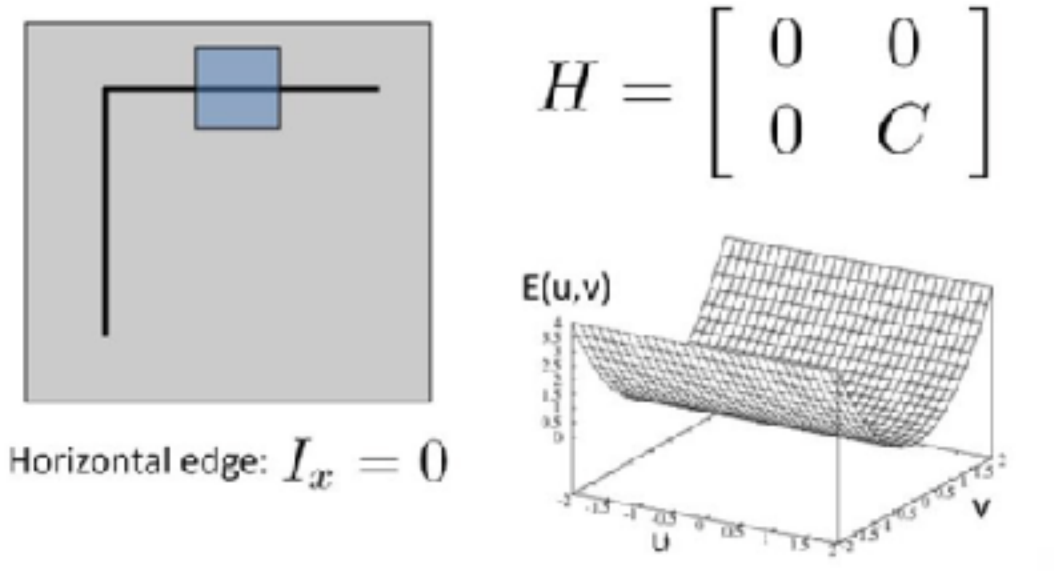
"edge": no change along the edge direction

"corner": significant change in all directions

Harris Corner Detector



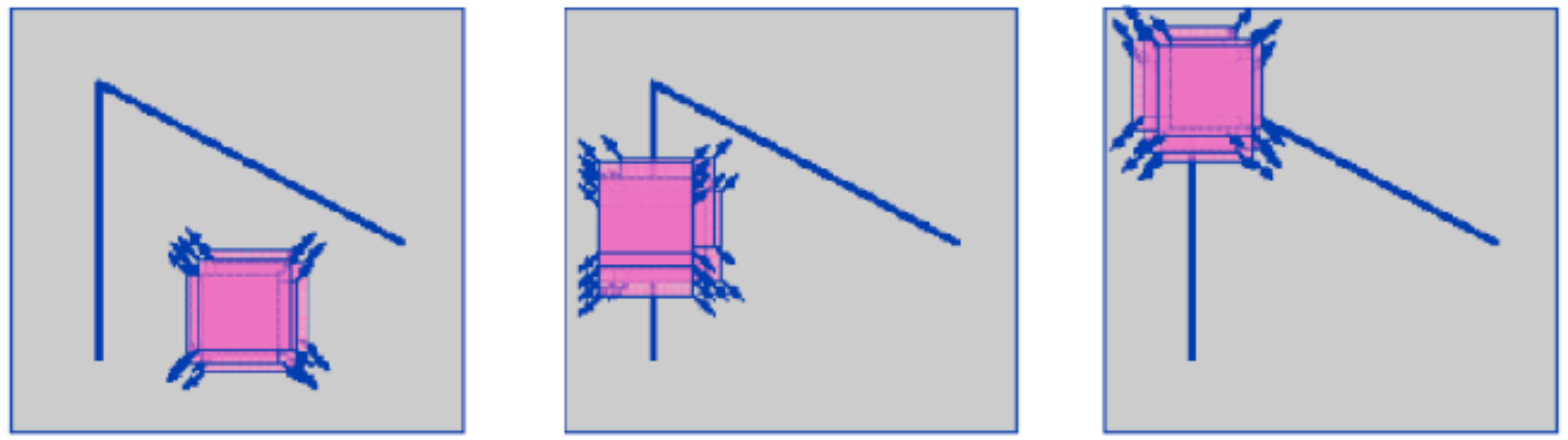
Harris Matrix Eigenvalues



Corner Detector and Features

What are corners?

Auto-correlation



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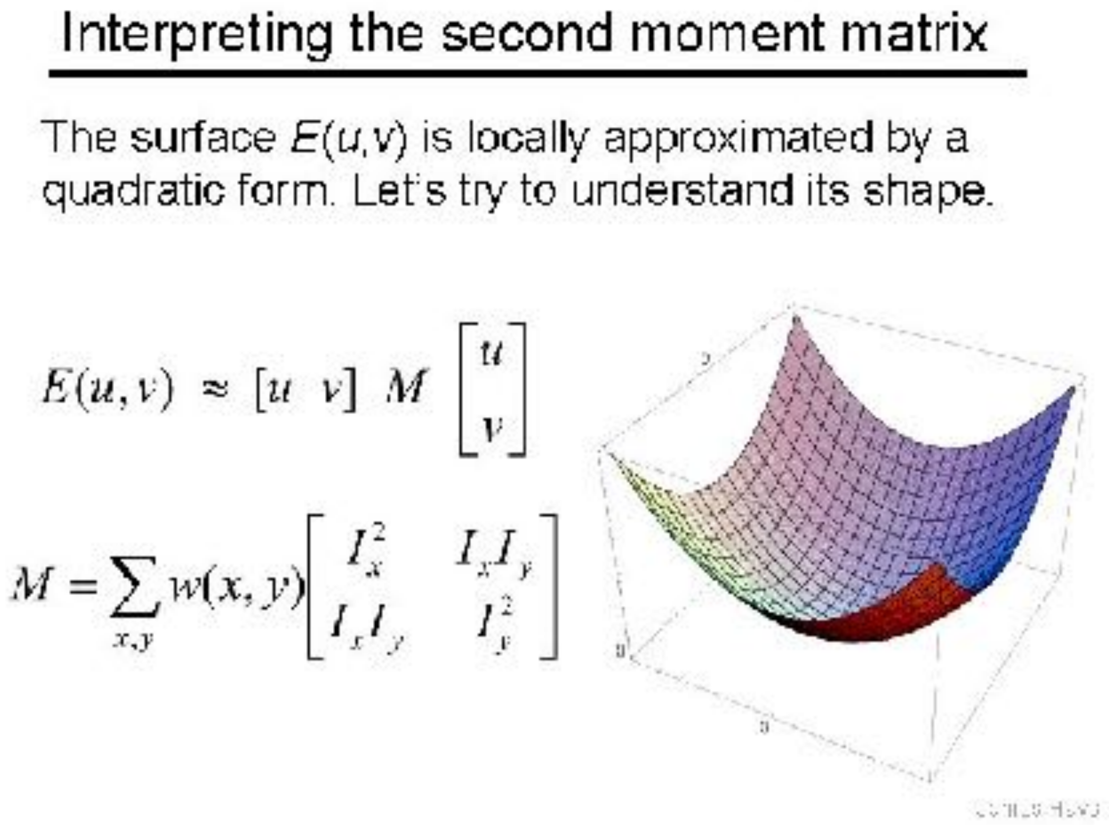
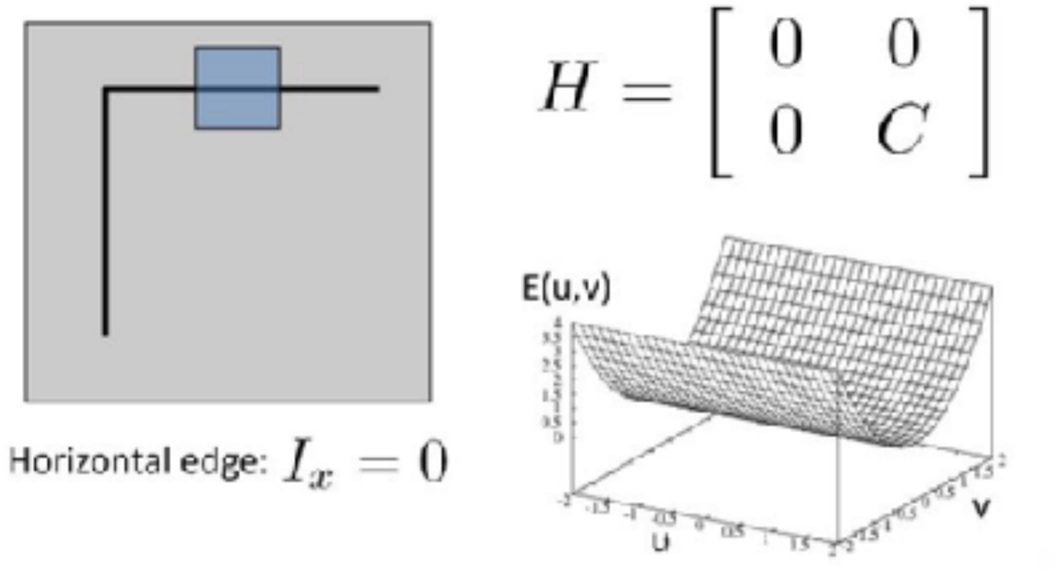
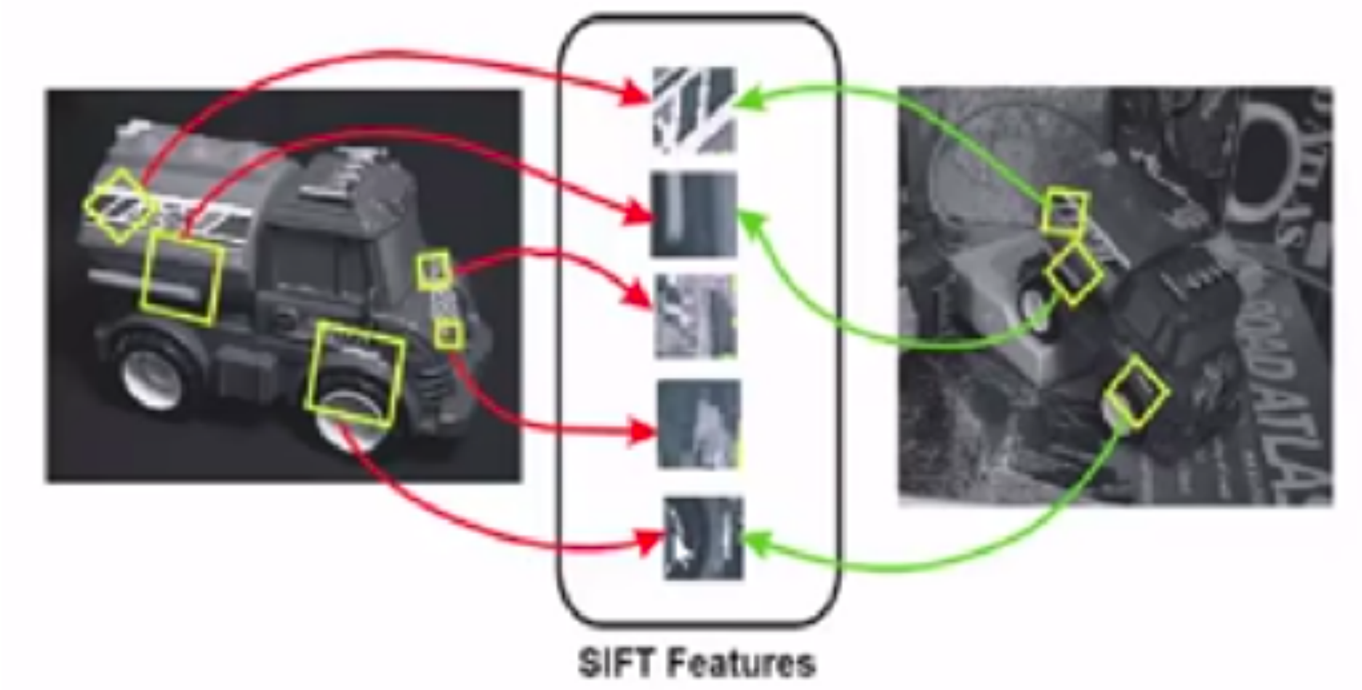


Harris Matrix Eigenvalues

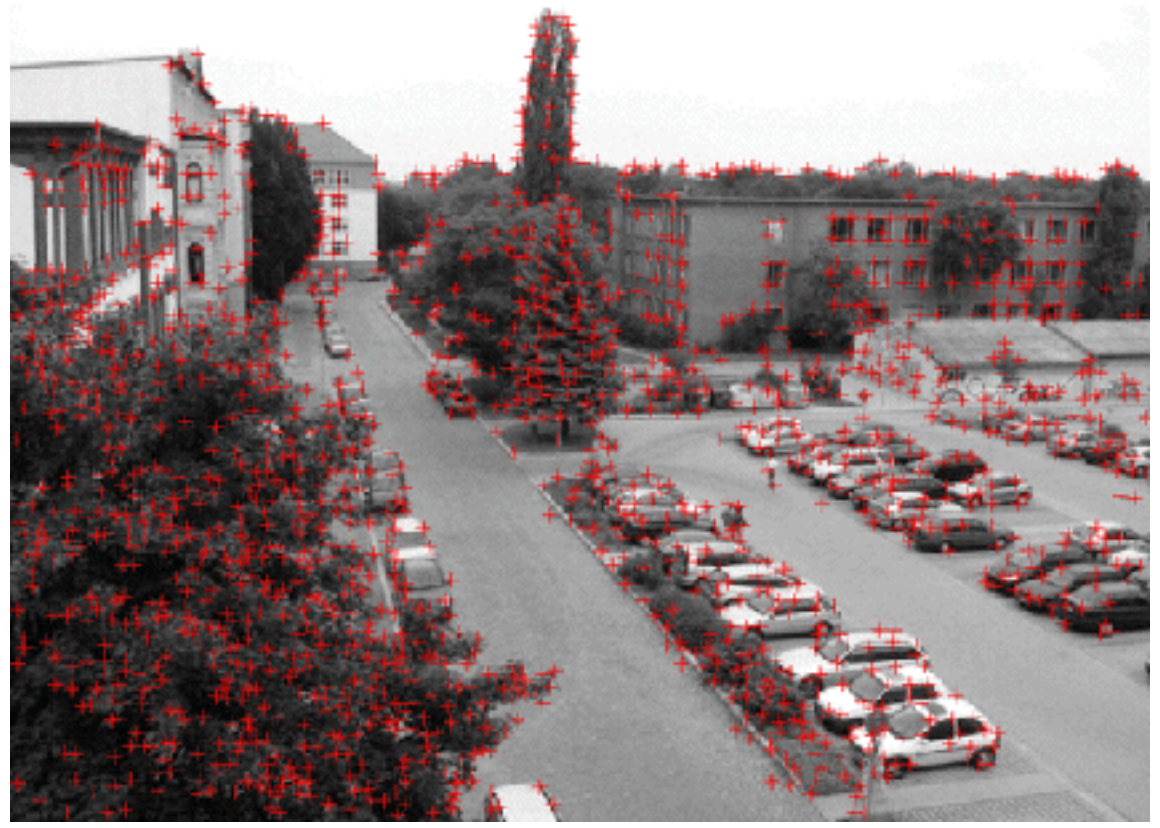


SIFT

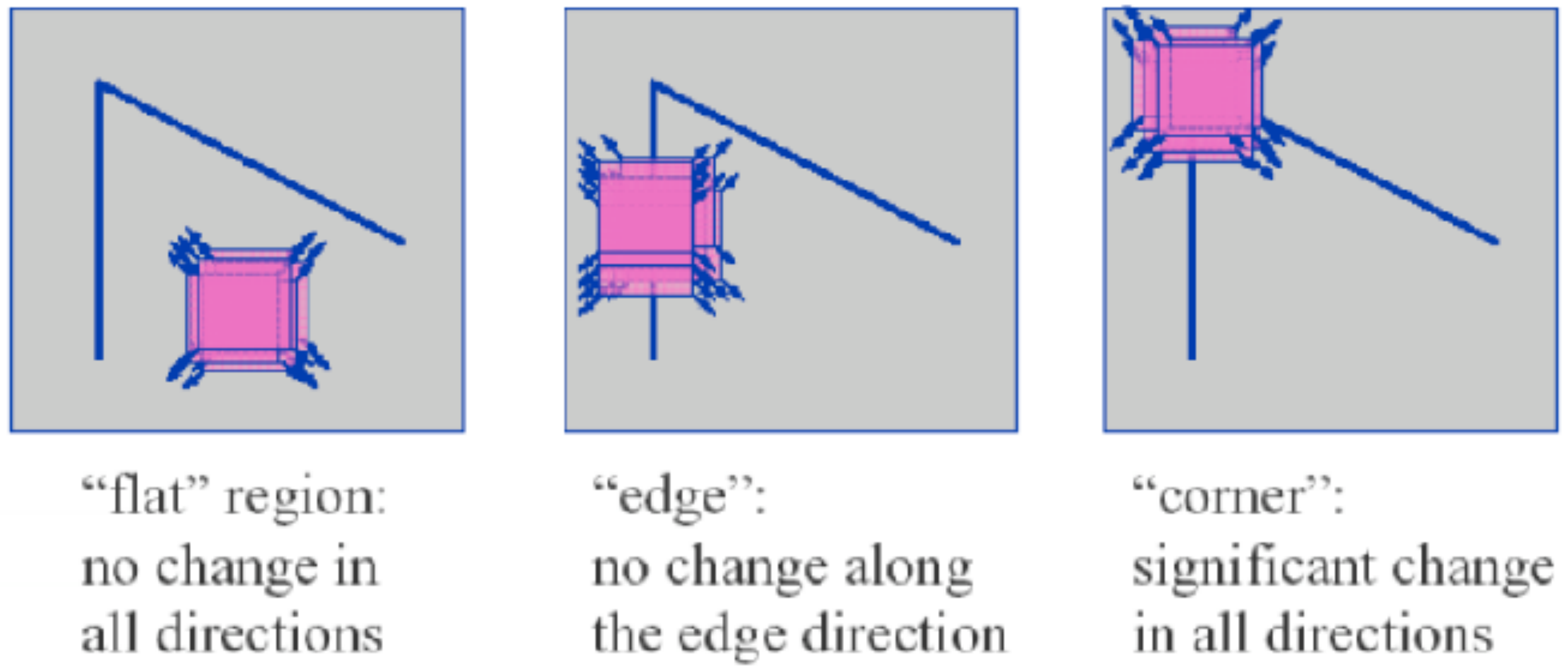


Corner Detector and Features

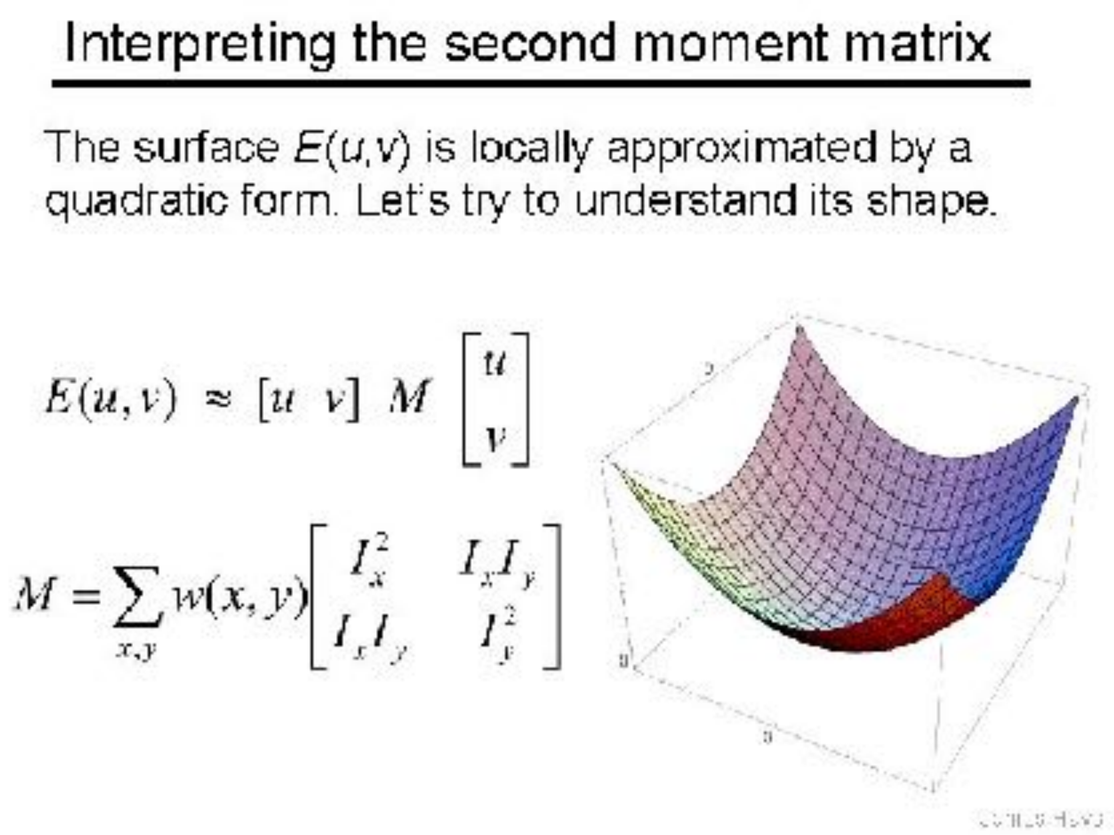
What are corners?



Auto-correlation



Harris Corner Detector



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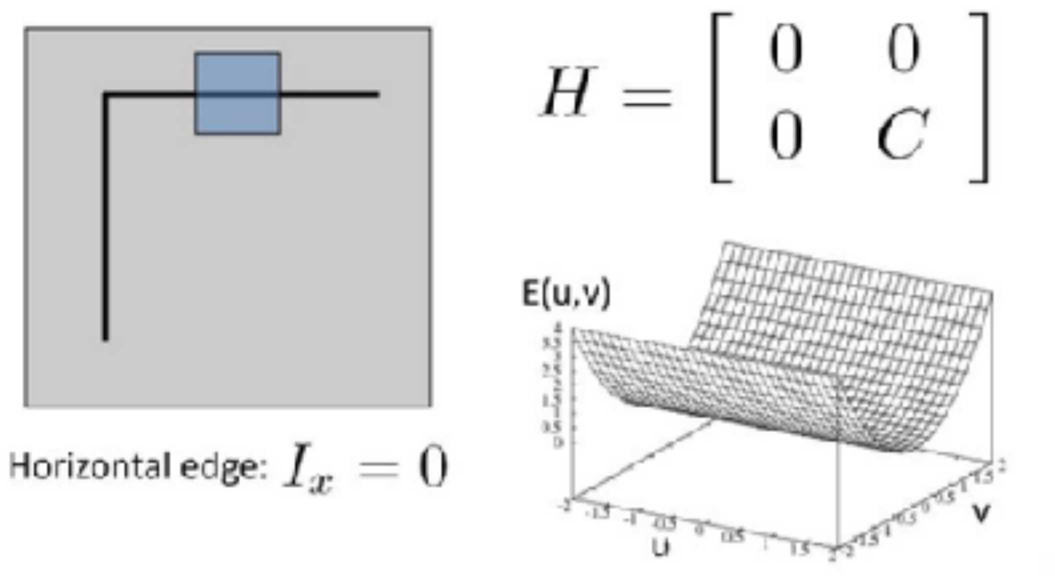

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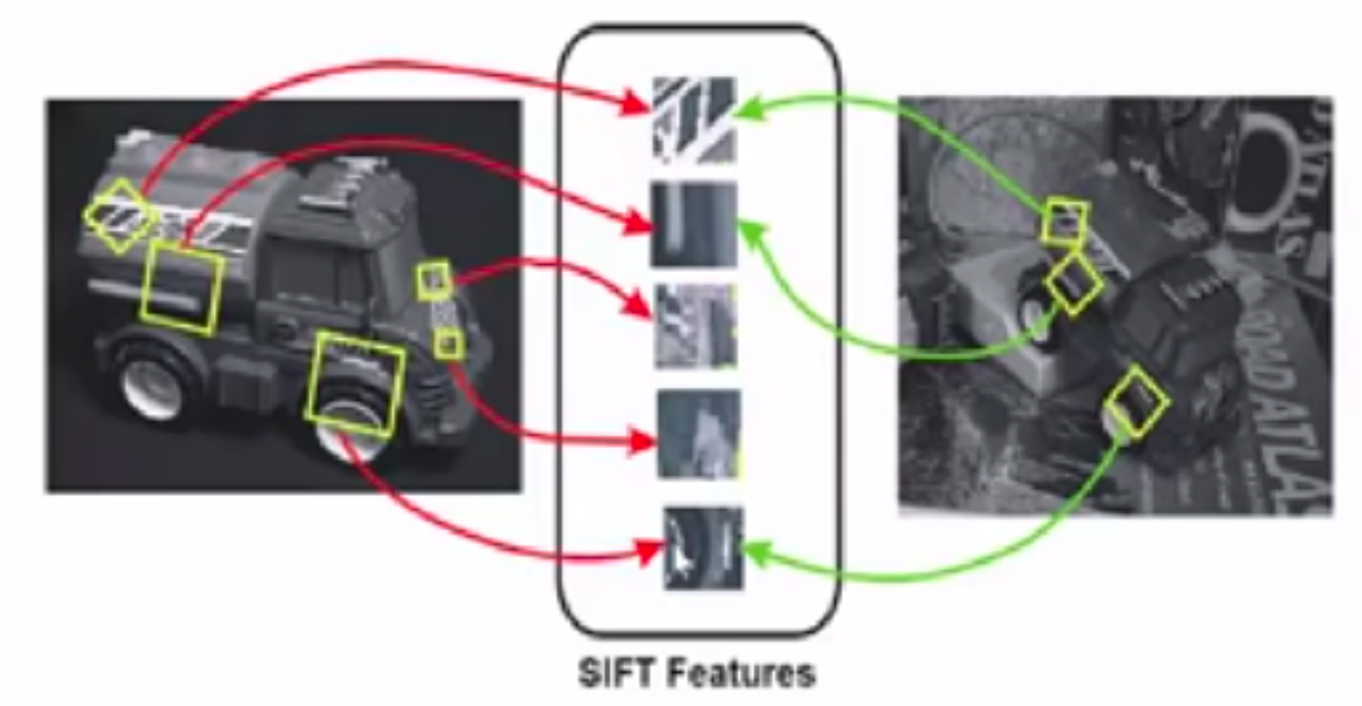

Susan/Fast

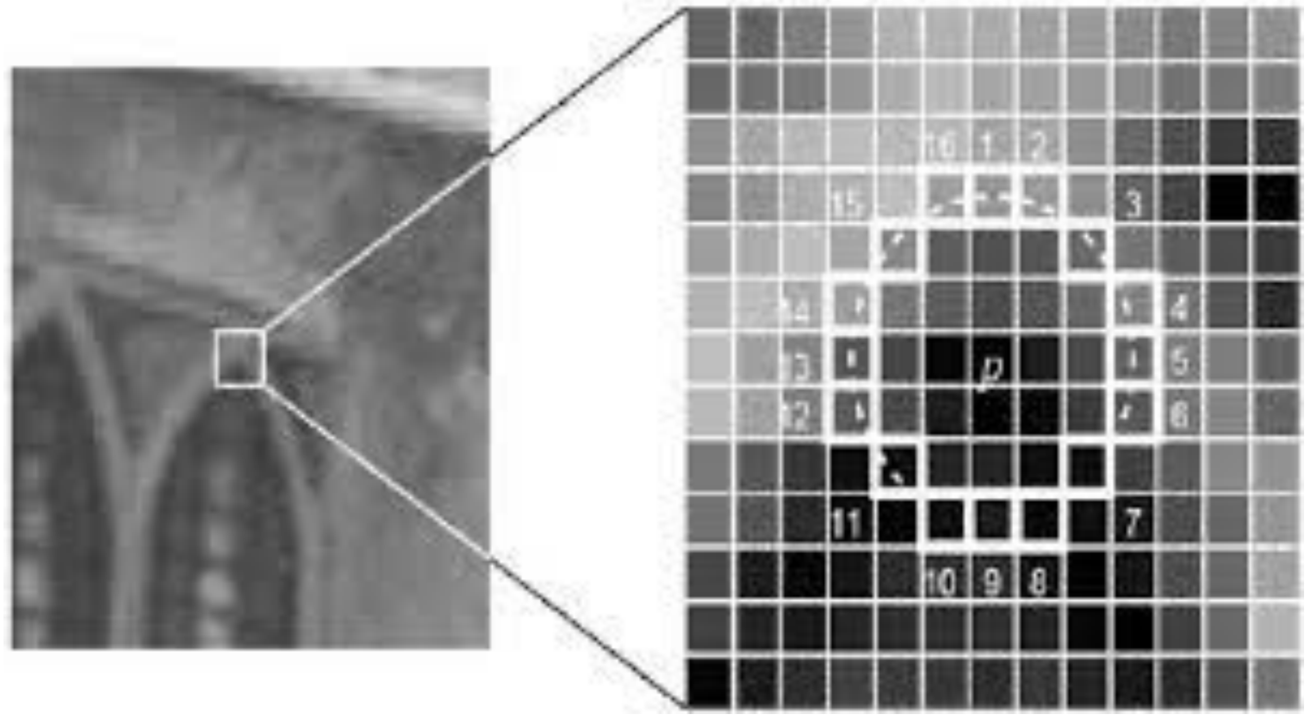

Image Matching

Image Matching

Template matching and tracking

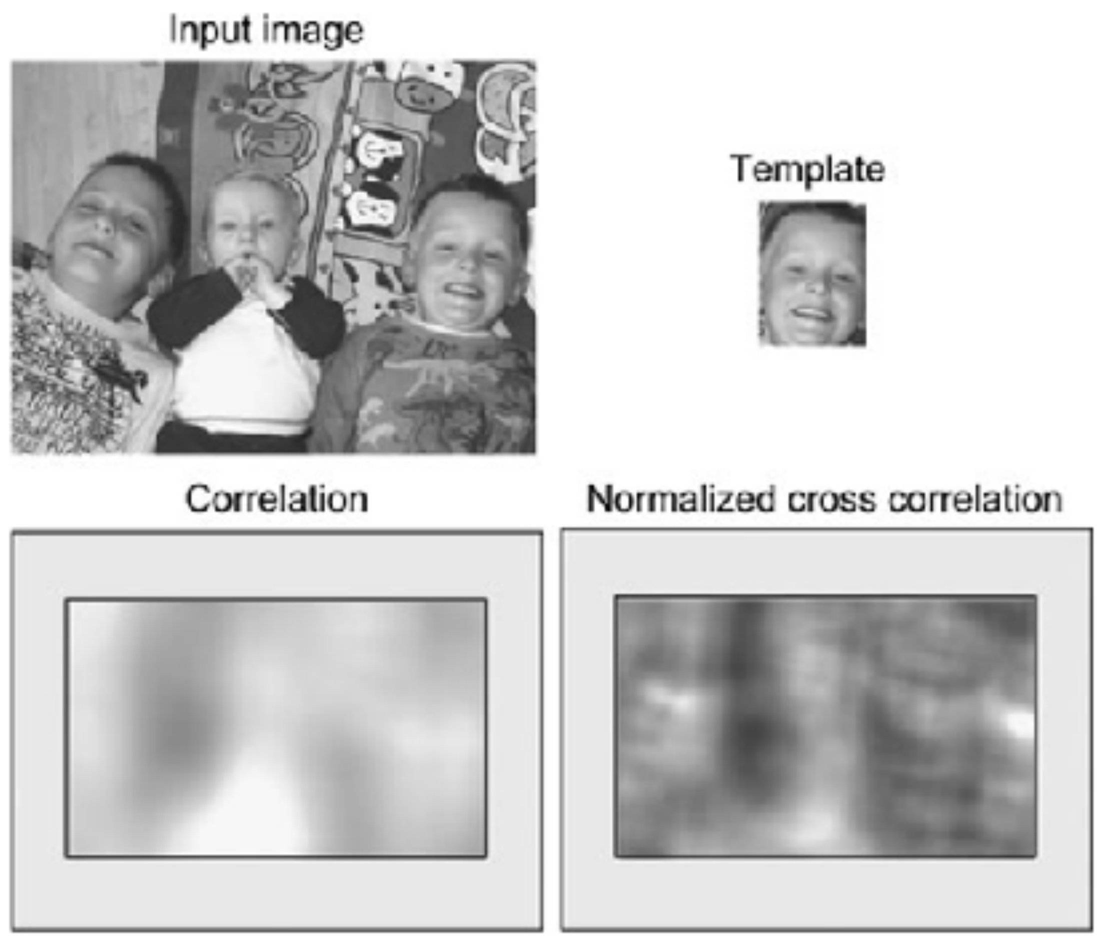

Image Matching

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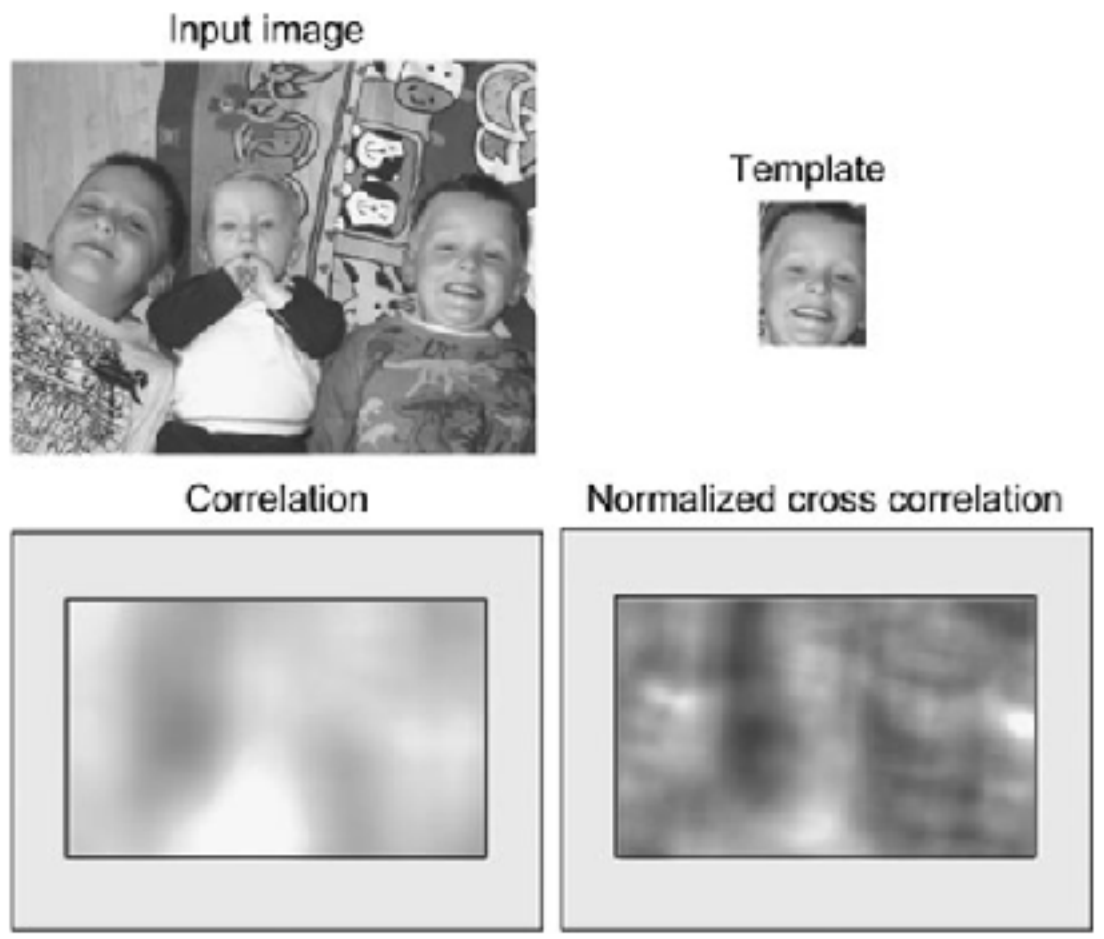


SSD/NCC

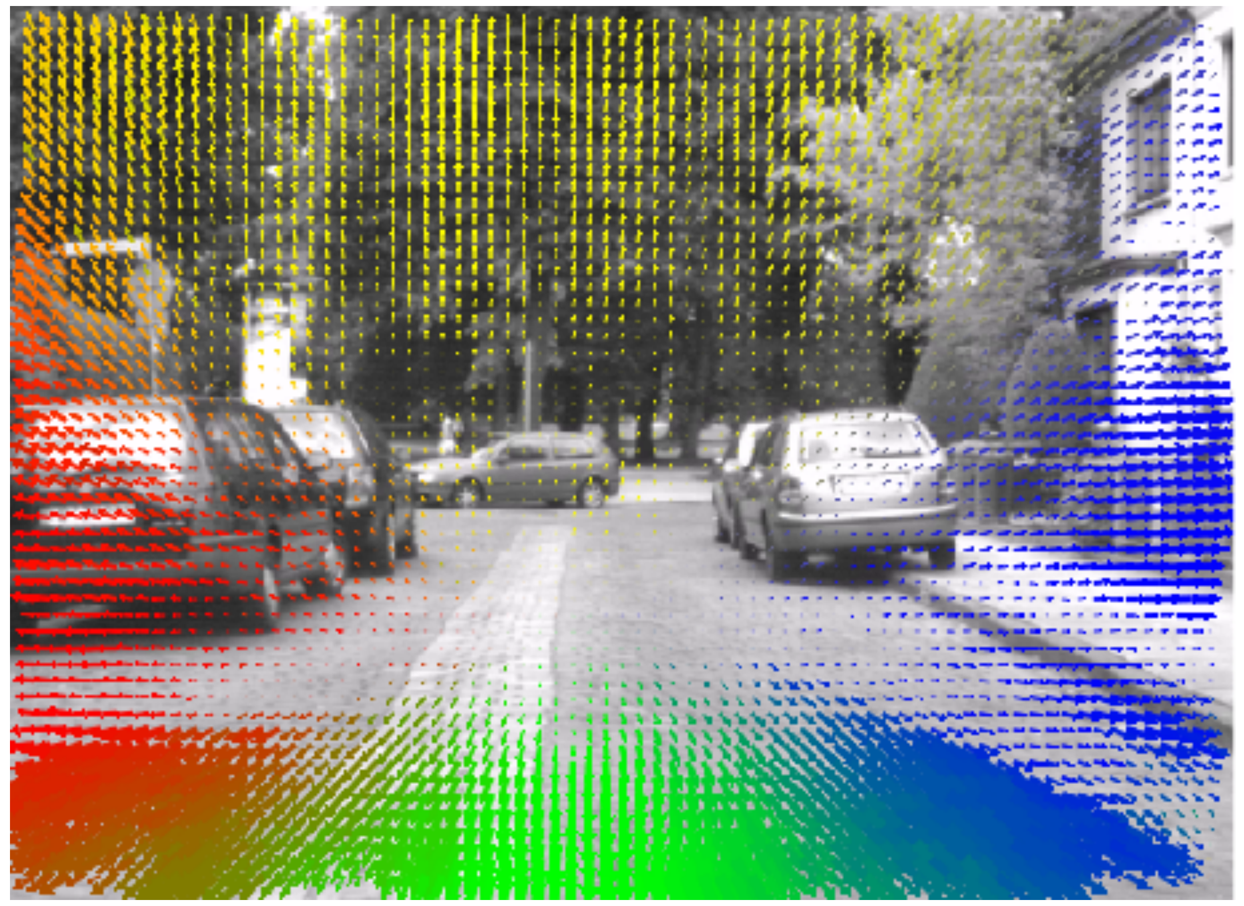
Image **similarity**

Name	Measure	Toolbox function
SAD	$s = \sum_{(u,v)\in\mathbf{I}} \lvert \mathbf{I}_1[u,v] - \mathbf{I}_2[u,v] \rvert$	`sad()`
SSD	$s = \sum_{(u,v)\in\mathbf{I}} (\mathbf{I}_1[u,v] - \mathbf{I}_2[u,v])^2$	`ssd()`
ZNCC	$s = \dfrac{\sum_{(u,v)\in\mathbf{I}} \mathbf{I}_1[u,v] \cdot \mathbf{I}_2[u,v]}{\sqrt{\sum_{(u,v)\in\mathbf{I}} \mathbf{I}_1^2[u,v] \cdot \sum_{(u,v)\in\mathbf{I}} \mathbf{I}_2^2[u,v]}}$	`zncc()`

Optical Flow

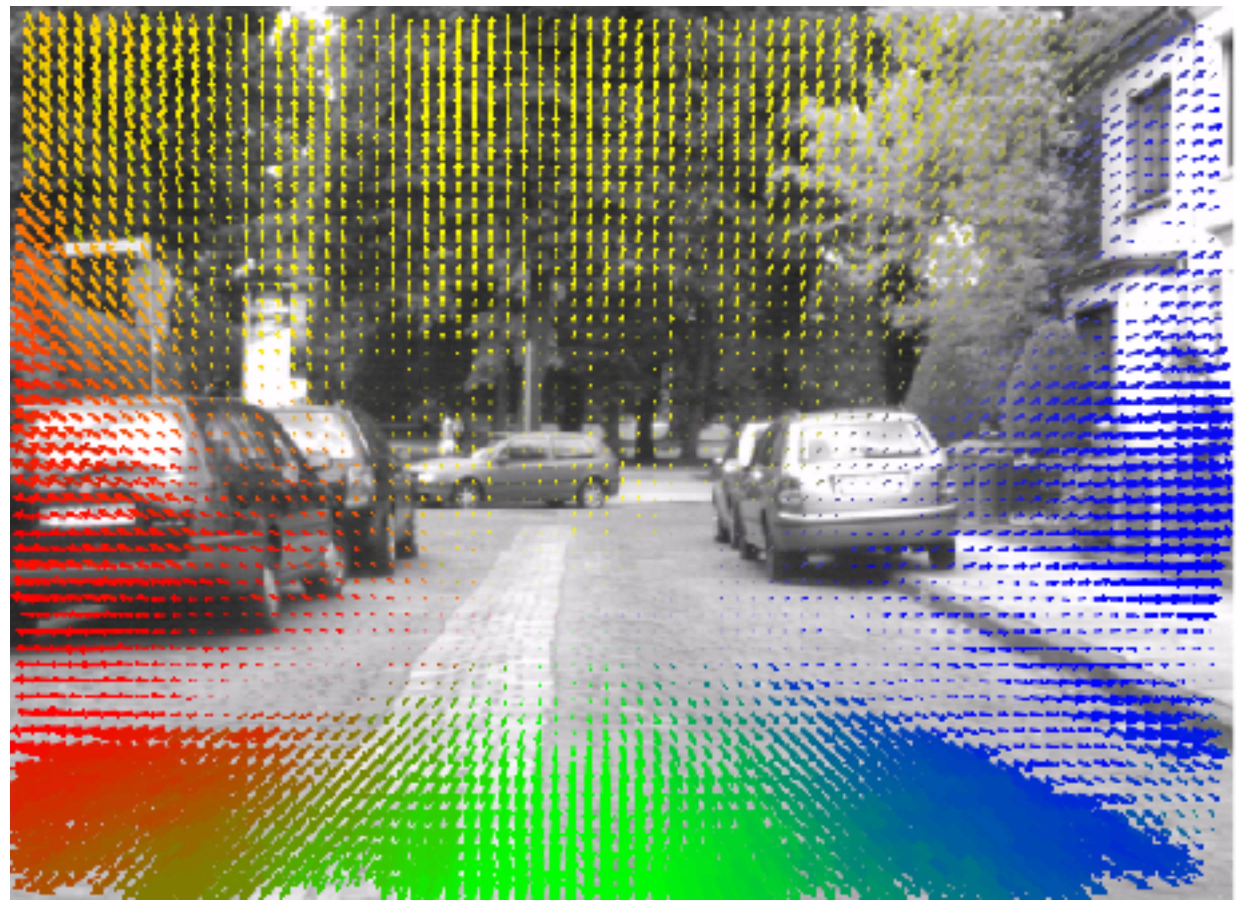
Optical Flow

Problem setup



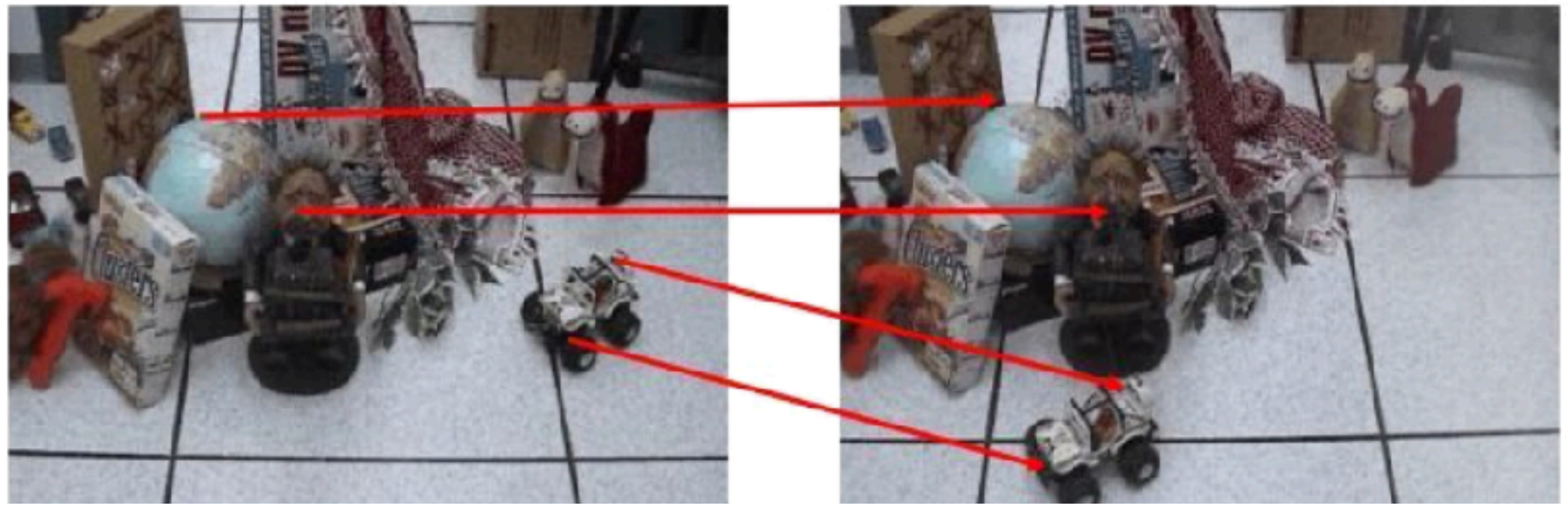
Optical Flow

Problem setup



Brightness constancy

Where did each pixel in image 1 go to in image 2



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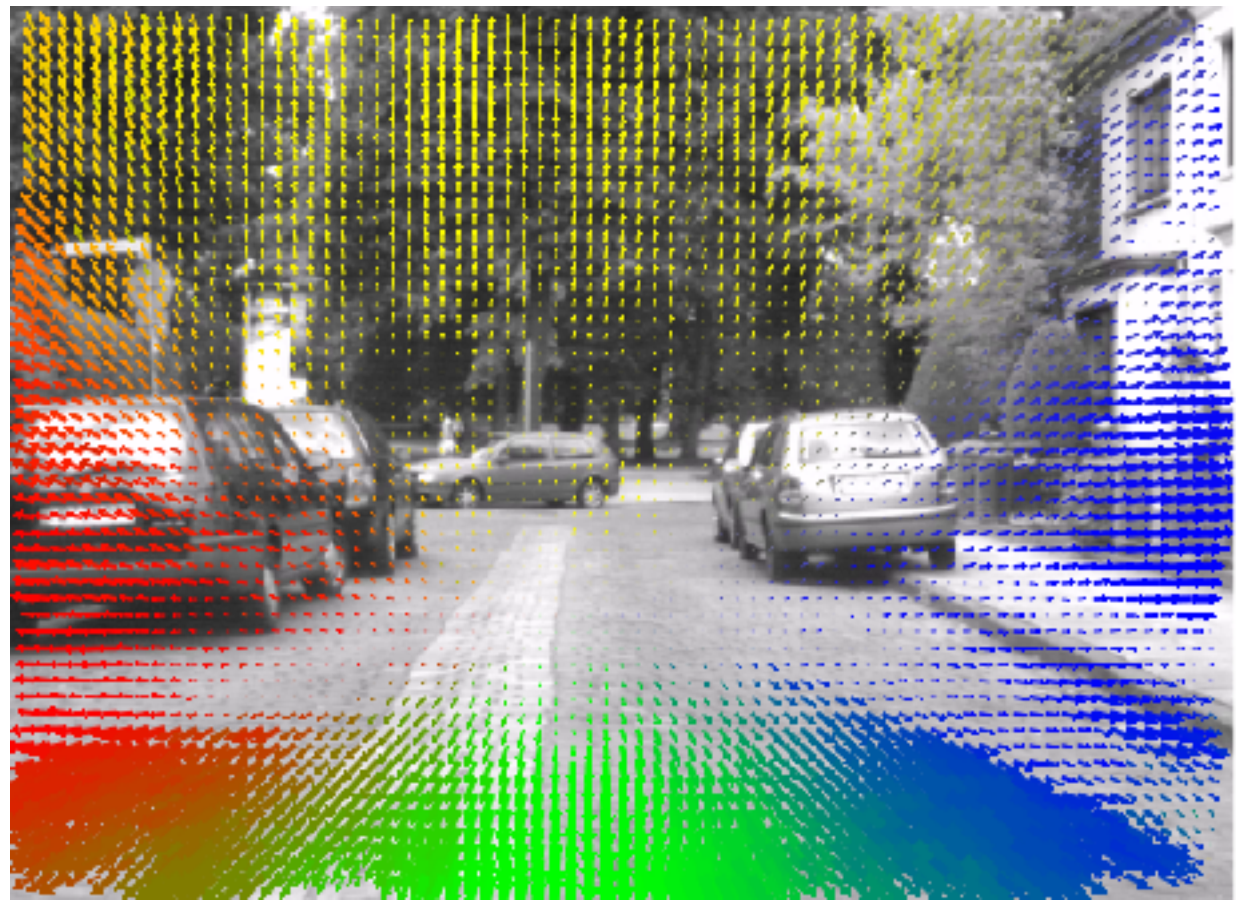
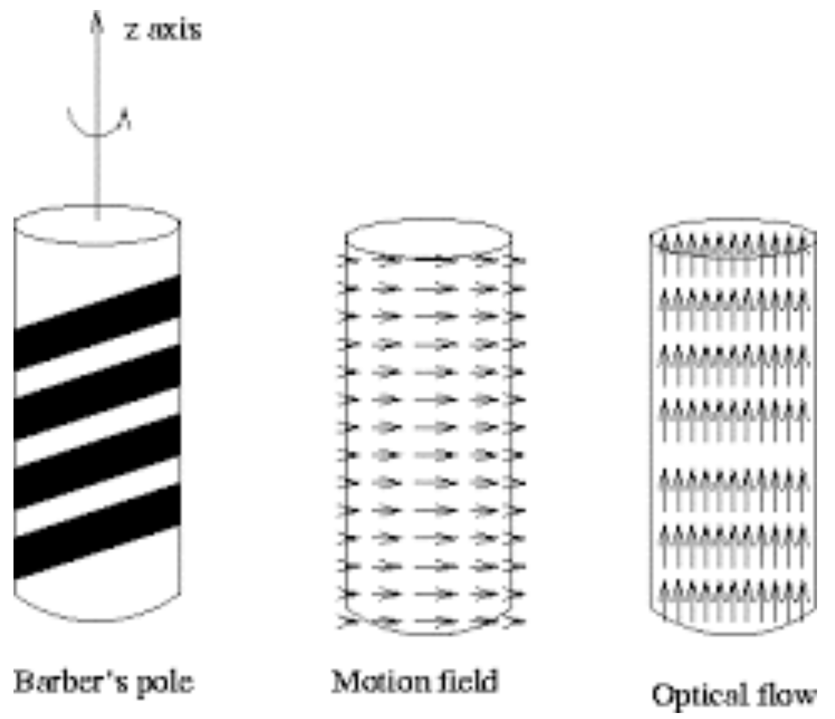


Aperture problem



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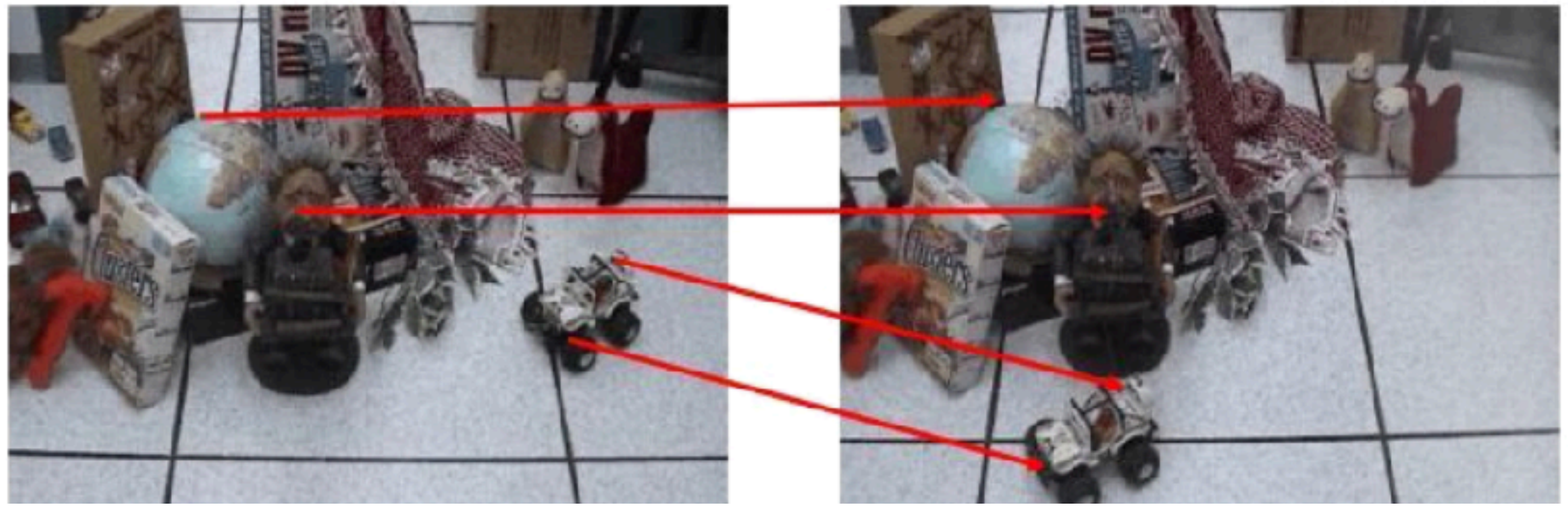

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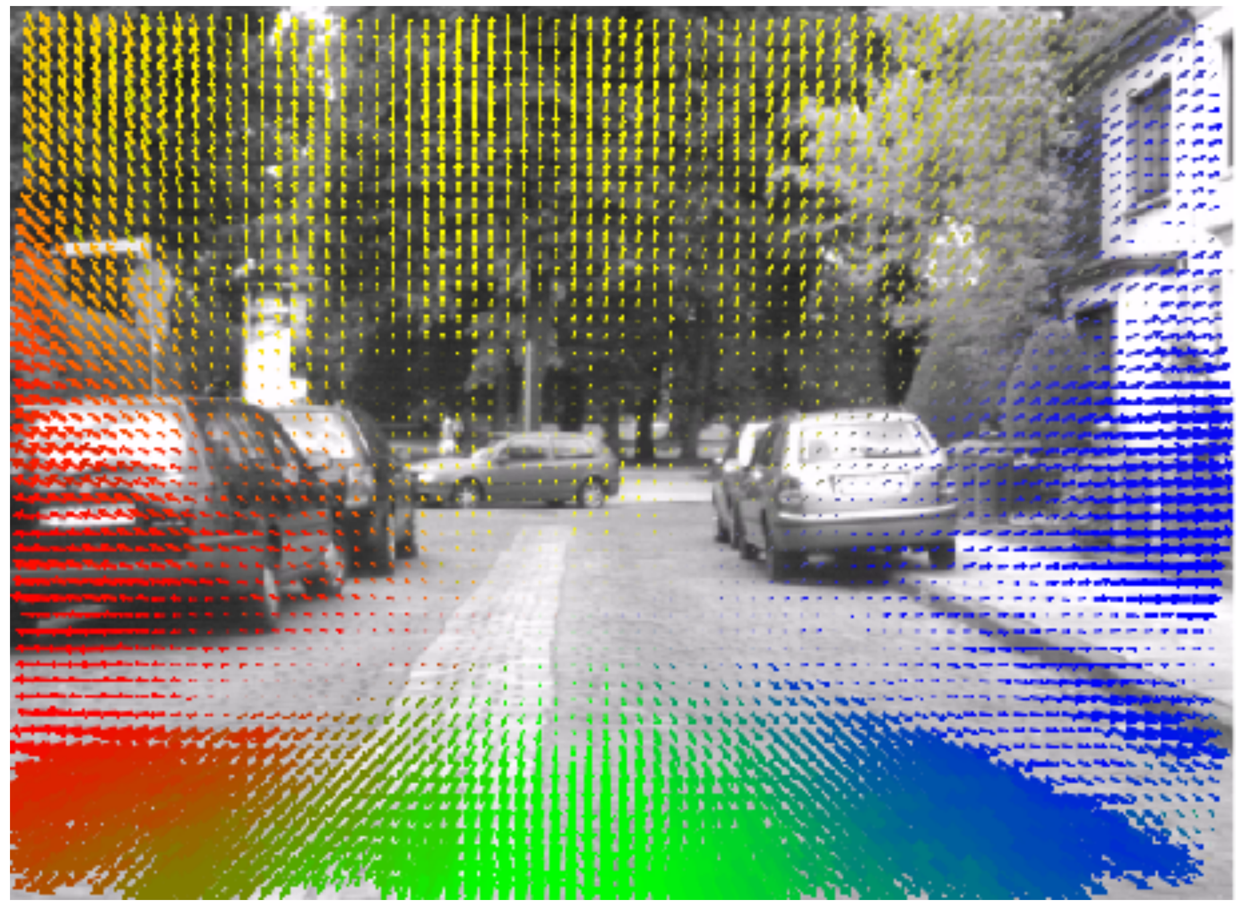

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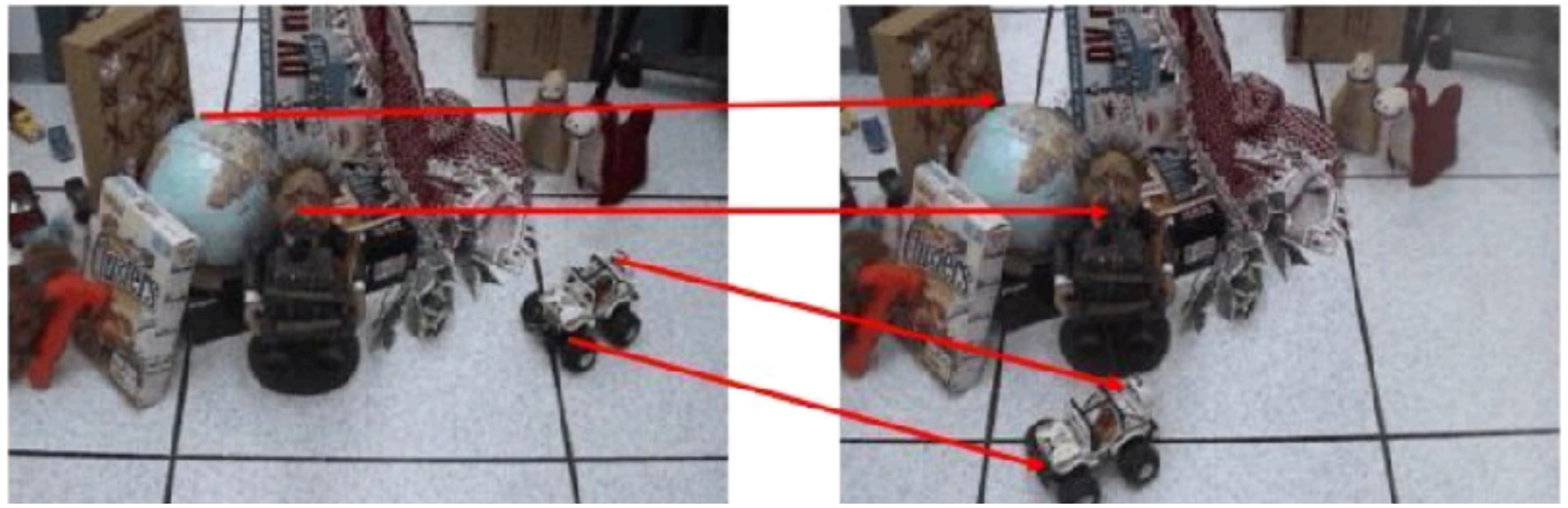

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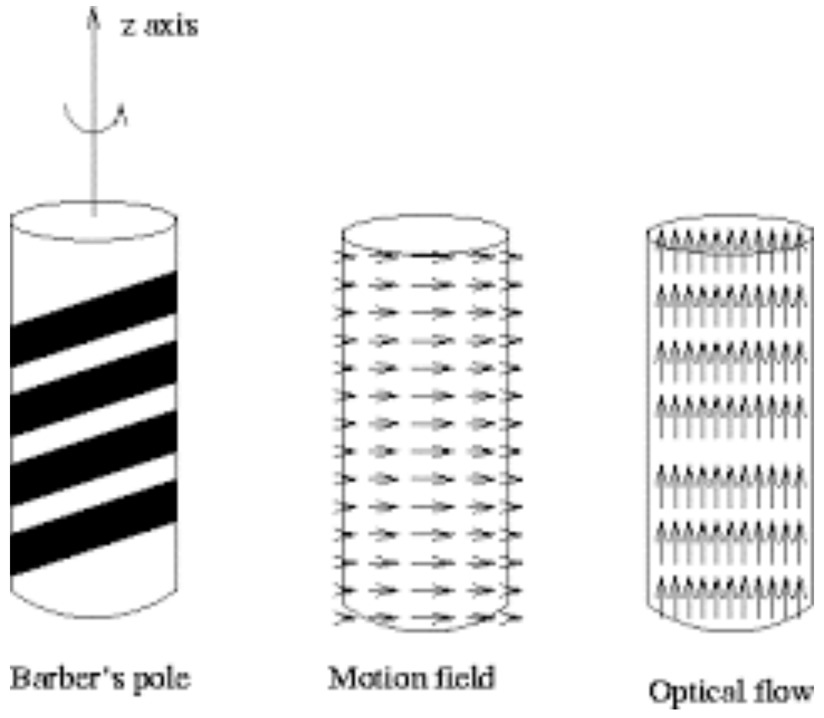
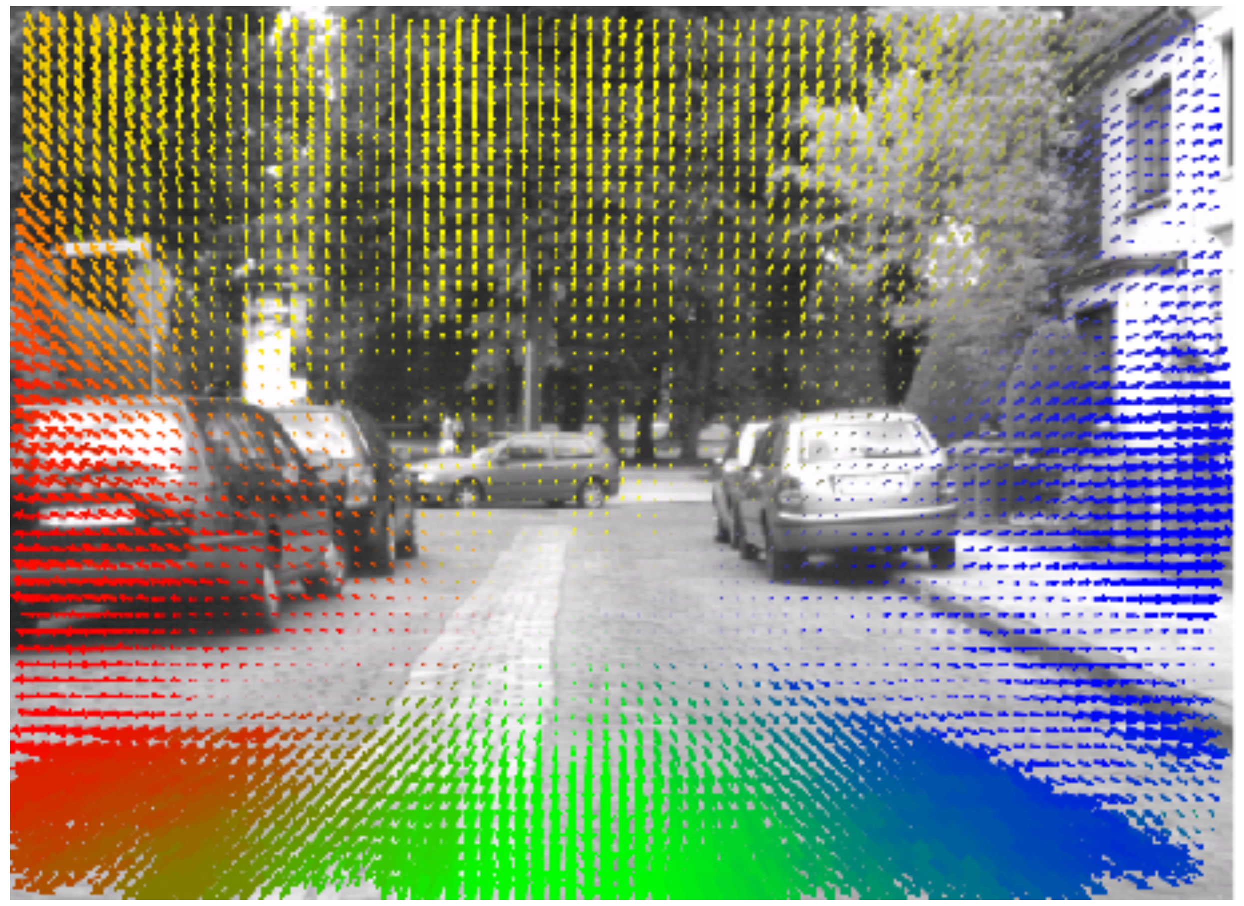


Optical flow equation

$$\frac{d\mathbf{I}}{dx}u + \frac{d\mathbf{I}}{dy}v + \frac{d\mathbf{I}}{dt} = 0$$

Optical Flow

Problem setup



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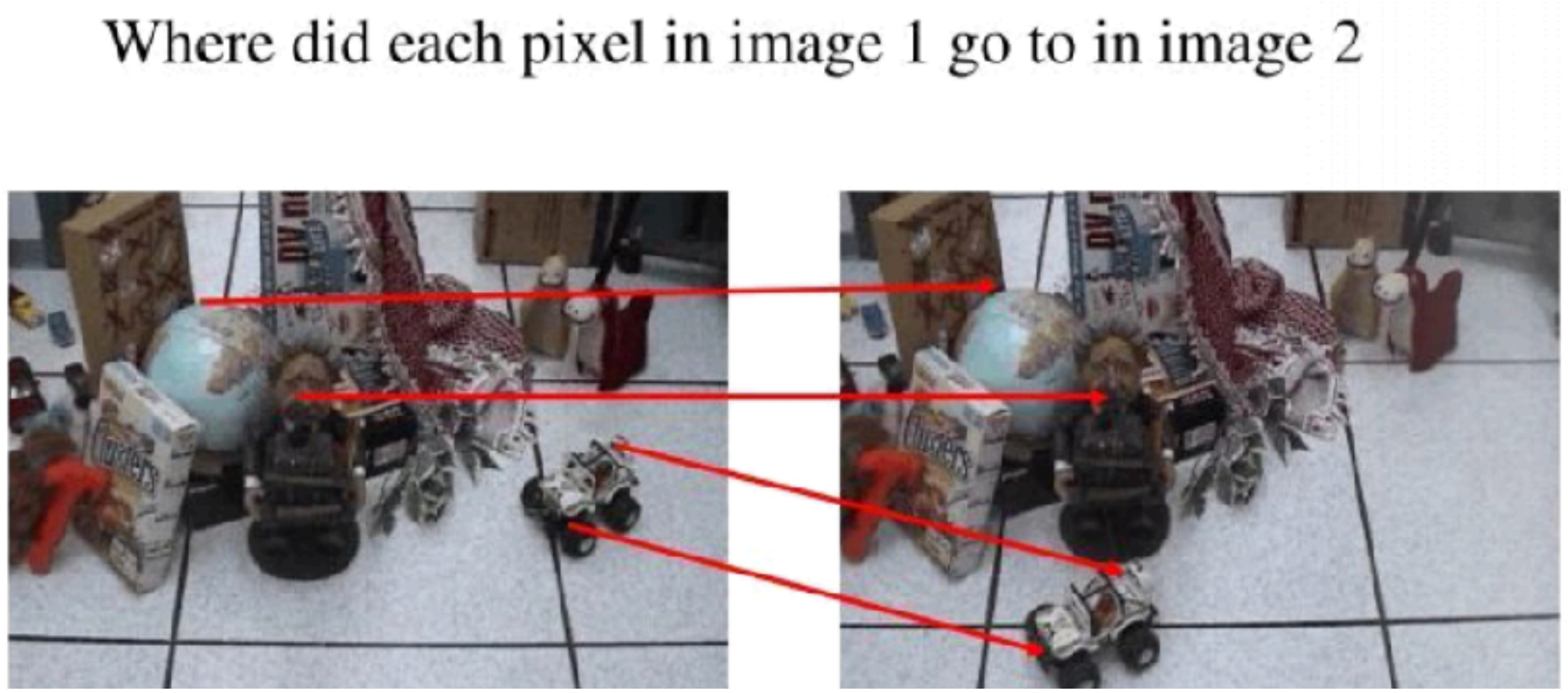

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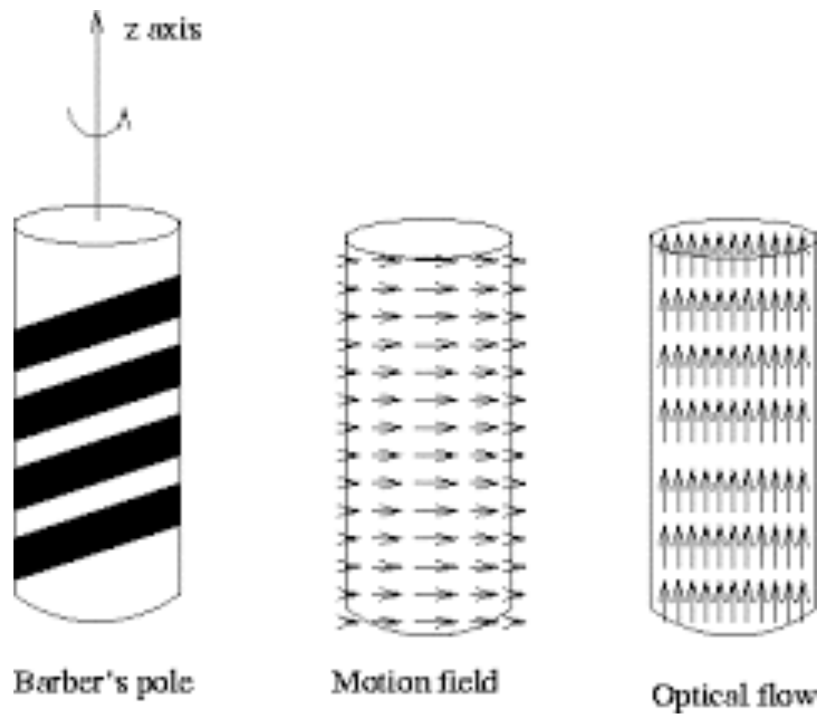

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Lucas-Kanade algorithm

Two-way Communication

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- I am teaching this course after 10 years!

- Our aim is to introduce you to the world of Image Processing

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- You are invited/encouraged to give feedback

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- I am teaching this course after 10 years!

- Our aim is to introduce you to the world of Image Processing

- You are invited/encouraged to give feedback
  - On-line forum (via Moodle)
  - Speak up. Please send us your criticism/comments/suggestions
  - Ask questions, please!

- Thanks to many people who helped so far with slides/comments

People

Niloy Mitra

Tobias Ritschel

Mirgahney Mohammed
Daniele Giunchi
Hengyi Wang

Timetable

- Thursday 10:00-11:00 (Anatomy G04 Gavin de Beer LT)
- Friday 11:00-13:00 (Chadwick G07)
- Lab session Thursday 16:00-18:00

Course Logistics

- Lectures + QA sessions + lab sessions
- Grading: 2 courseworks (10% + 10%) (date to be announced)
- Project (80%)
- Expect to spend a lot of time on this course. Rewarding but we need your participation and sustained effort.
- Lecture slides and video — available on Moodle
- Reachable via email