Digital image processing and analysis
2. What digital images are like

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Previous lecture:

- Basics of visual perception
- Digital image acquisition
- Inside digital cameras
- Imaging devices

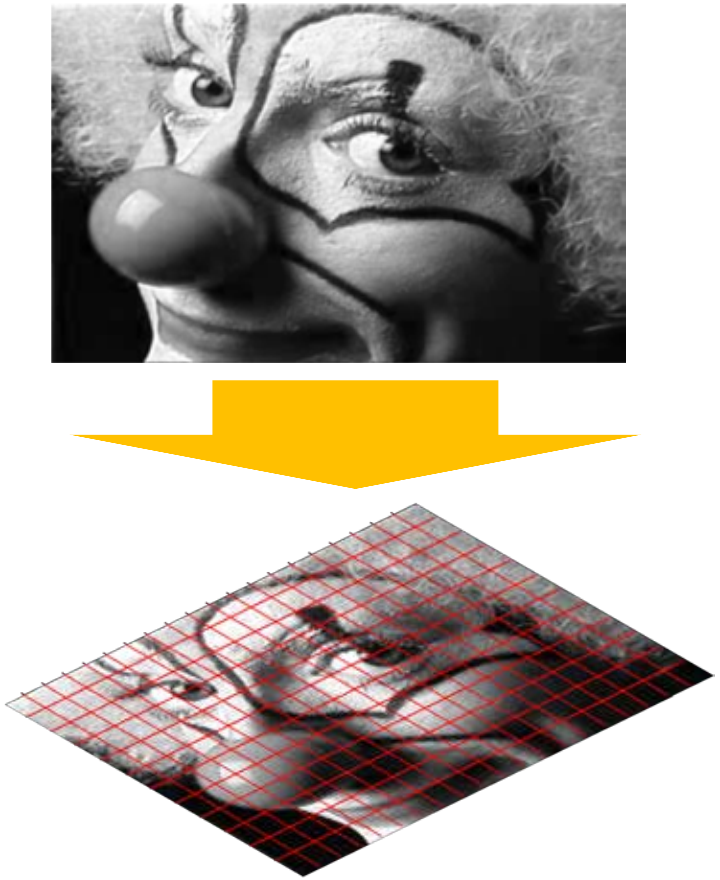
... and how these two compare

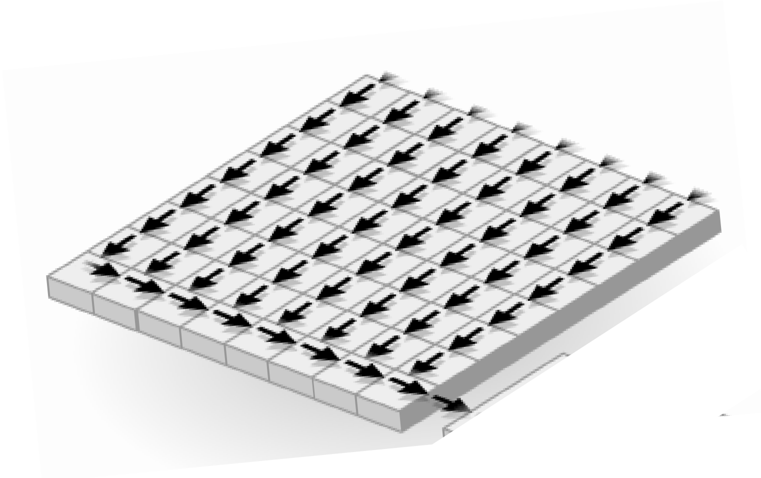
In this lecture we shall find out about:

- Digital image properties
  - **Computer representation** – pixels
  - **Sampling** – related to image coordinates
  - **Quantisation** – related to image values
- … and how they relate to image acquisition

Digital image

Real world object / analogue image is projected onto a sensor array





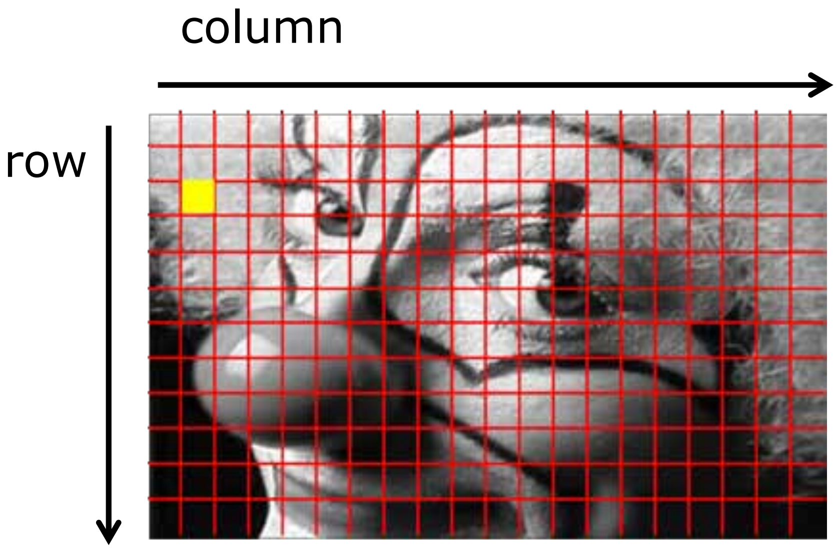
CCD

Digital image

- Stored as a rectangular grid of picture elements (pixels)

- Grid has
  - Width
  - Height
  - Spatial resolution

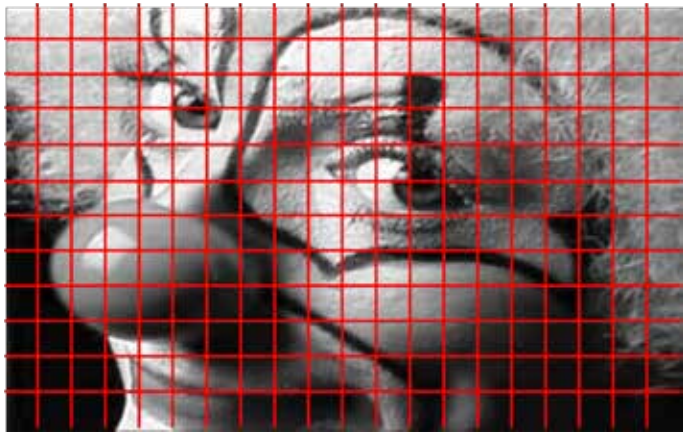
- Pixel has
  - Location (row, column)
  - Value

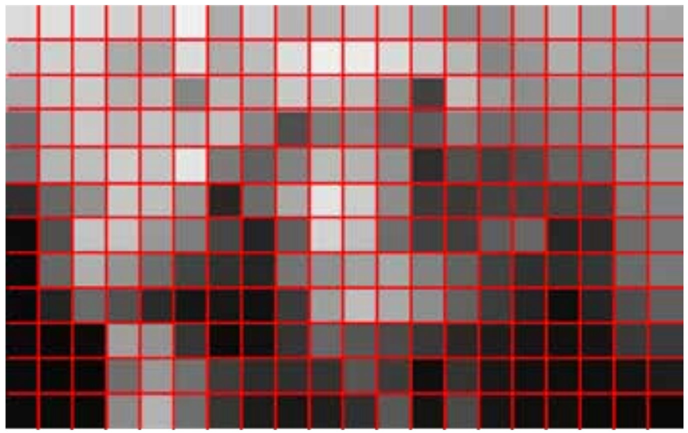


Digital image
Pixel resolution and spatial resolution

- Pixel resolution
  - The number of pixel columns (width) and the number of pixel rows (height), e.g. 640 × 480
  - Total number of pixels in the image, e.g. 640 × 480 = <u>307,200</u>

- Spatial resolution (sampling frequency)
  - The number of independent pixel values per unit length



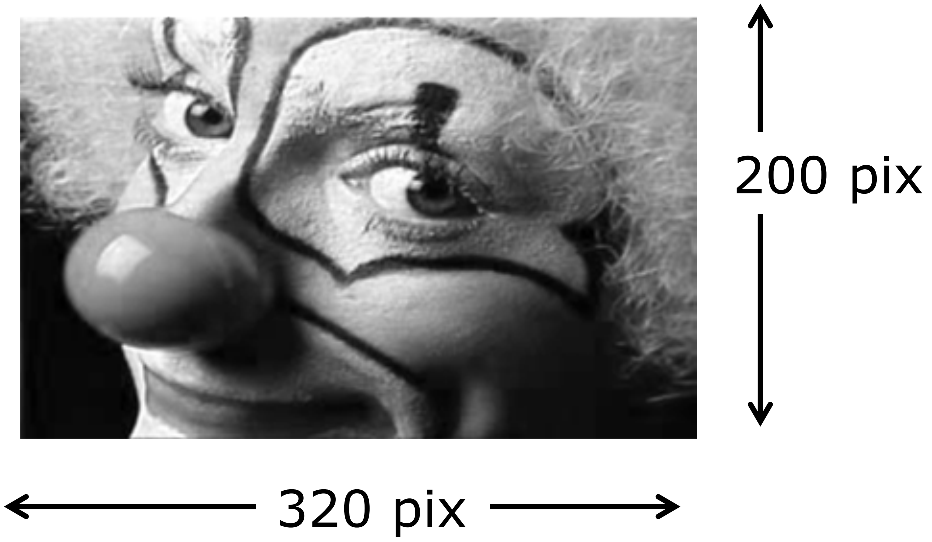


Digital image

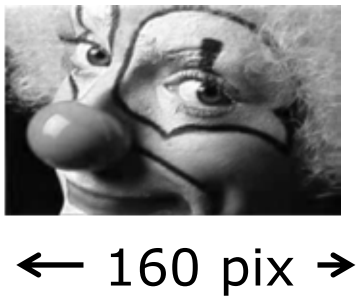
Sampling: image size and spatial resolution

Real world size: 320 x 200 mm

Displayed image size: 320 x 200 mm



Displayed image size: 160 x 100 mm



Real size: 320 x 200 **mm**
Digital image size: 320 x 200 **pixels**
Spatial resolution: 1 **pixel per mm**

Real size: 320 x 200 **mm**
Digital image size: 160 x 100 **pixels**
Spatial resolution: 0.5 **pixels per mm**

Spatial resolution = sampling frequency

Digital image
Sampling: image size and spatial resolution

Real world size: 320 x 200 mm

Displayed image size: 320 x 200 mm

200 pix

320 pix

Magnified 160 x 320 image
Displayed image size: 320 x 200 mm

100 pix

160 pix

Real size: 320 x 200 **mm**
Digital image size: 320 x 200 **pixels**
Spatial resolution: 1 **pixel per mm**

Real size: 320 x 200 **mm**
Digital image size: 160 x 100 **pixels**
Spatial resolution: 0.5 **pixels per mm**

Spatial resolution = sampling frequency

Digital image
Sampling frequency

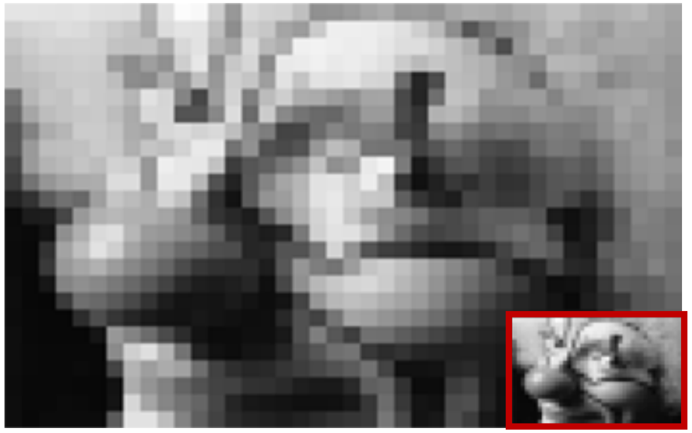
- Spatial resolution depends on how finely the image is sampled during digitization.
- Higher spatial resolution images have a greater number of pixels for the same physical size.
- When a real-world data is under-sampled, detail can be lost or obscured.
- When it is over-sampled, storage is wasted.
- To accurately preserve the spatial resolution *sampling interval* should be equal to *half* the size of the smallest detail we wish to preserve (the **Nyquist criterion**).
- Sampling interval is the inverse of the sampling frequency.

Digital image
Effect of reducing sampling frequency

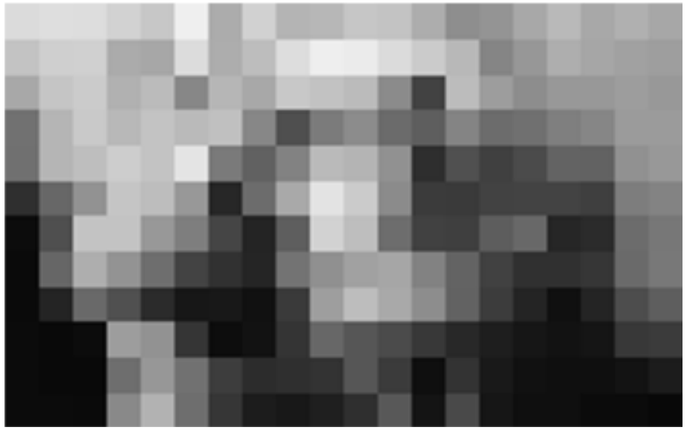
1 pixel / mm
= 1 mm/pixel

0.5 pixel / mm
= 2 mm/pixel

Display size is the same



0.25 pixels / mm
= 4 mm/pixel

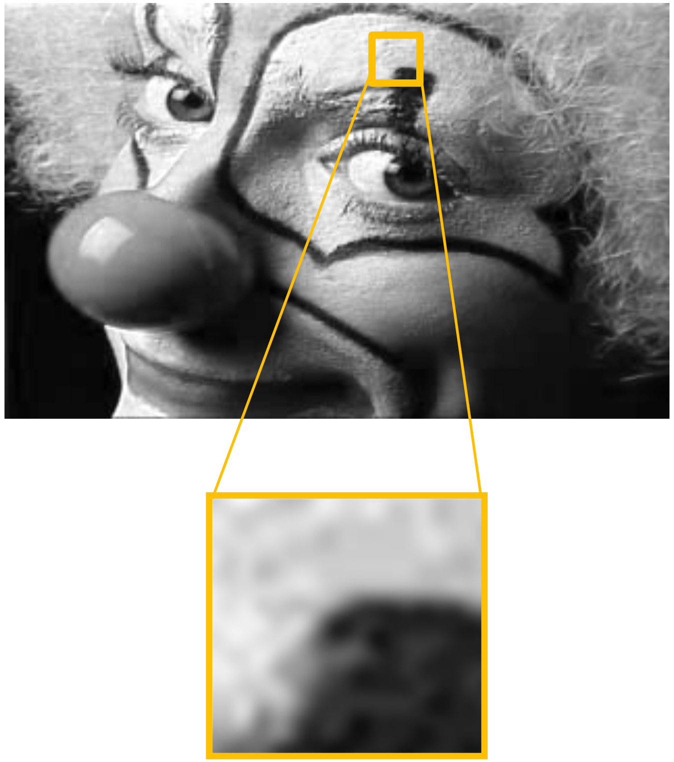


0.125 pixels / mm
= 8 mm/pixel

Digital image
Quantisation

- The intensity of light falling on a pixel is digitised and recorded as a digital number.
- A digital number is stored with a finite number of bits (binary digits).
- The number of bits determine the **radiometric resolution** of the image.
- The detected intensity value needs to be scaled and quantized to fit within the range of value available for storage.

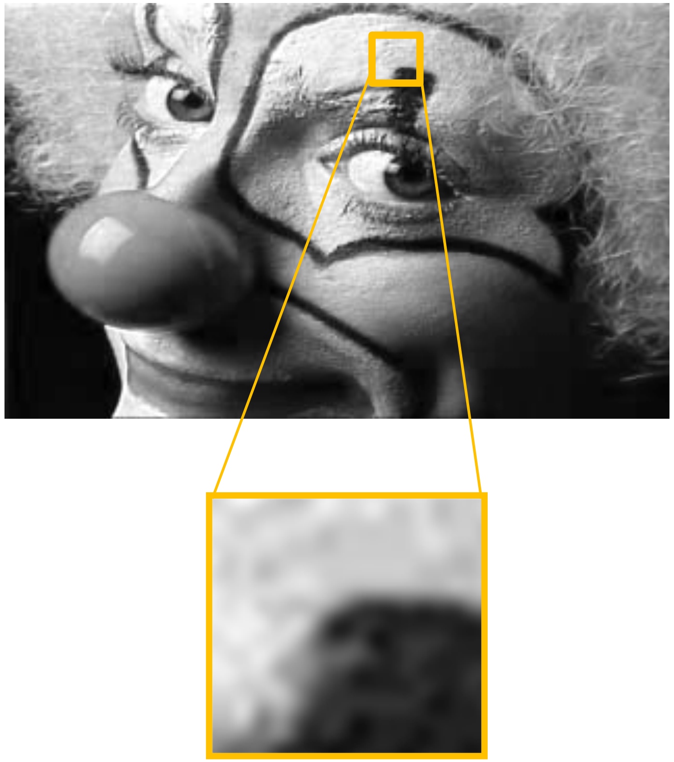
Digital image
Quantisation: pixel values



228	224	216	204	199	202	207	197	207	215	207	208	204	198	184	192
218	206	199	200	207	210	208	202	212	218	215	210	201	188	174	197
200	200	203	204	204	199	197	207	210	203	196	191	194	193	193	198
209	219	221	211	201	203	213	200	200	190	188	184	193	197	203	205
223	225	223	208	186	176	176	173	176	171	178	180	194	201	212	198
200	191	184	167	127	76	42	63	63	57	68	81	112	136	156	169
212	214	182	91	41	49	49	38	40	42	40	37	38	50	61	95
216	198	136	65	60	62	24	34	41	46	42	36	34	37	40	42
205	181	141	101	96	84	46	40	48	50	40	34	37	38	33	35
181	150	128	96	64	44	33	38	49	46	34	32	43	45	37	37
193	153	100	65	48	39	36	36	44	42	32	35	46	46	34	34
197	159	90	62	56	48	44	43	44	38	29	32	41	40	31	30

Higher value = brighter

Digital image
Quantisation: pixel values



228	224	216	204	199	202	207	197	207	215	207	208	204	198	184	192
218	206	199	200	207	210	208	202	212	218	215	210	201	188	174	197
200	200	203	204	204	199	197	207	210	203	196	191	194	193	193	198
209	219	221	211	201	203	213	200	200	190	188	184	193	197	203	205
223	225	223	208	186	176	176	173	176	171	178	180	194	201	212	198
200	191	184	167	127	76	42	63	63	57	68	81	112	136	156	169
212	214	182	91	41	49	49	38	40	42	40	37	38	50	61	95
216	198	136	65	60	62	24	34	41	46	42	36	34	37	40	42
205	181	141	101	96	84	46	40	48	50	40	34	37	38	33	35
181	150	128	96	64	44	33	38	49	46	34	32	43	45	37	37
193	153	100	65	48	39	36	36	44	42	32	35	46	46	34	34
197	159	90	62	56	48	44	43	44	38	29	32	41	40	31	30

Higher value = brighter

Digital image
Quantisation: binary digits

8 bits per pixel

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
128	64	32	16	8	4	2	1

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	1	3
0	0	1	0	1	0	0	0	40
0	0	1	0	1	1	0	0	44
1	1	1	1	1	1	1	1	255

Example

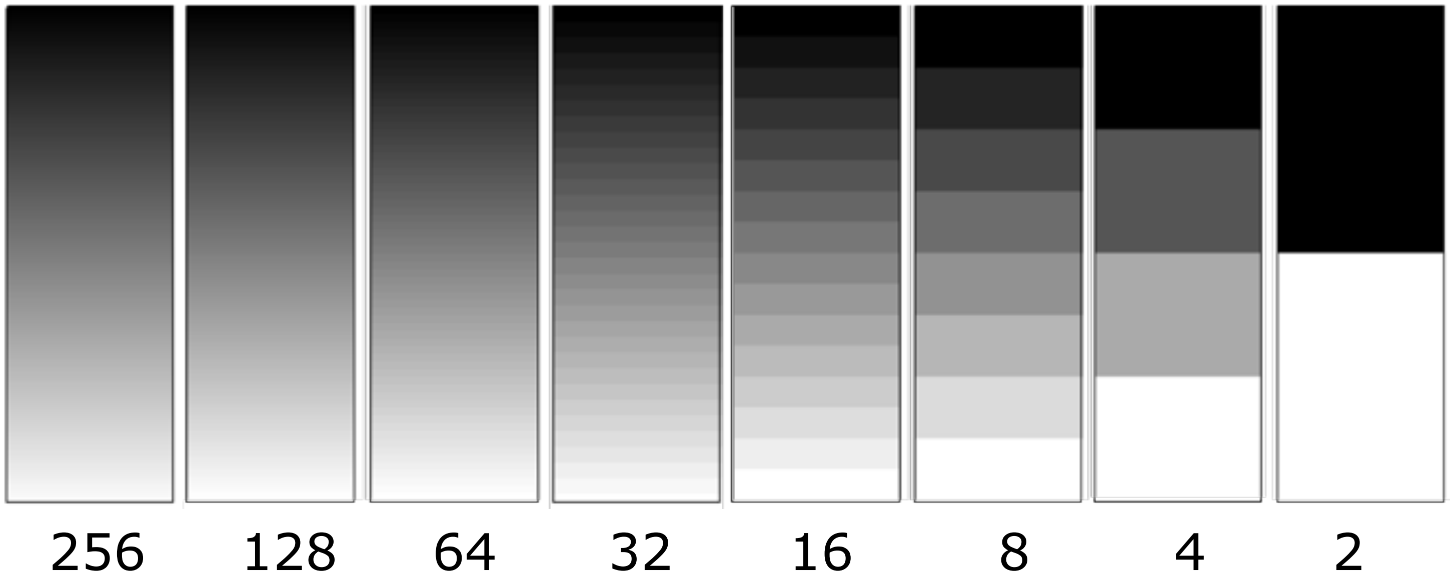
$$0*128 + 0*64 + 1*32 + 0*16 + 1*8 + 1*4 + 0*2 + 0*1 = 44$$

Digital image
Quantisation: binary digits

Bits per pixel	Min value	Max value	Number of quantization levels
1	0	1	1
8	0	255	255
12	0	4,095	4,095
16	0	65,535	65,535

Digital image
Quantisation: radiometric resolution

- Radiometric resolution: the smallest change in intensity level that can be detected by the sensing system.
- Limited by the number of discrete quantization levels used to digitize the continuous intensity value.



Digital image
Quantisation: radiometric resolution

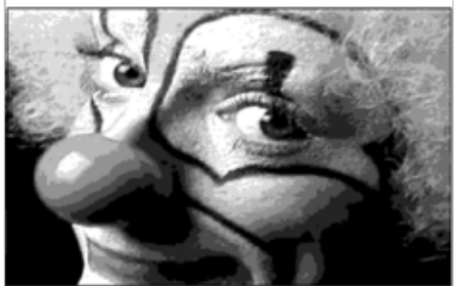
256

128

64

32

16



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At how many b.p.p. you start noticing the difference?

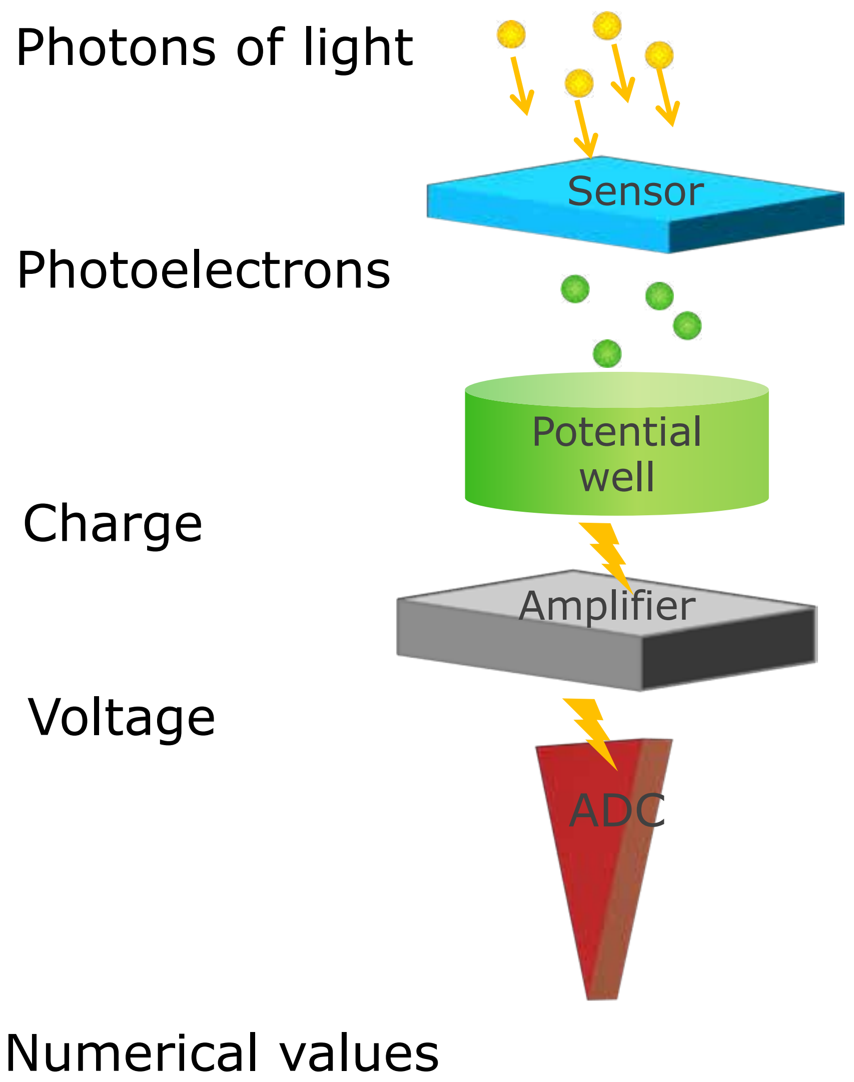
Digital image
Dynamic Range and Full Well Capacity

- The dynamic range of a sensor is defined as the **full-well** capacity divided by the camera noise.

$$dyn_{CCD} = 20 \cdot \log\left(\frac{\text{fullwell capacity}\,[e^-]}{\text{readout noise}\,[e^-]}\right)[dB]$$

- It relates to the ability of a camera to record simultaneously very low and very bright light signals.
- When the well reaches the full capacity the charge starts to fill adjacent pixels, resulting in **blooming**.

Pathways (Lecture 1)



Charge generation

Collection and storage of liberated charge

Charge transfer

Charge measurement

ADC=Analogue-to-Digital Converter

Digital image
Dynamic Range and Full Well Capacity

table 2: dynamic range of binary resolution

resolution [bit] $x \Rightarrow 2^x$	dynamic range A/D conversion [digitizing steps]	dynamic range A/D conversion [dB]
8	256	48.2
10	1 024	60.2
12	4 096	72.3
14	16 384	84.3
16	65 536	96.3

https://www.pco-tech.com/fileadmin/user_upload/db/download/kb_dynamic_range_20100813.pdf

In this lecture we have covered:

- Digital image properties
  - **Computer representation** – pixels
  - **Sampling** – related to image coordinates
  - **Quantisation** – related to image values
- … and how they relate to image acquisition

Next lecture:

- FIJI (ImageJ) image processing and analysis software

- Essentials
- Basic concepts
- Overview of functions and tools
- Macros and programming

- You can download your own copy:
  https://imagej.net/Fiji/Downloads

Further reading and experimentation

- **Sampling frequency**: http://micro.magnet.fsu.edu/primer/java/digitalimaging/processing/samplefrequency/index.html

- **Spatial and brightness resolution**: http://micro.magnet.fsu.edu/primer/digitalimaging/digitalimagebasics.html

- **Spatial and brightness resolution, interactive tutorials**: http://micro.magnet.fsu.edu/primer/java/digitalimaging/processing/bitdepth/index.html
- http://micro.magnet.fsu.edu/primer/java/digitalimaging/processing/spatialresolution/index.html