Introduction

DD2423 Image Analysis and Computer Vision

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General course information

This year the course will be fully online, except for the exam (maybe)

- 7.5 hp course (labs 4.0 hp, exam 3.5 hp)
- Course Web in Canvas under course code DD2423
- 2-3 lectures a week
- 16 lectures in total (3 exercise sessions)
- TAs: Wenjie, Taras, Jesper, Marcus, Zehang, Olga, Ioanna, Lihao, Muhammad, Zihan, Kyle and possible others.
- If you have questions: preferably use Canvas.

Assessment

- 3 labs (LAB1) and exam (TEN1)
- Grading: A-F
  - Final grade: average of exam and labs, rounded towards exam
  - Labs grade: average of labs, rounded towards nearest grade
- Labs are done in Matlab, possibly on your own laptop.
- There are scheduled times for labs:
  - This year all sessions are fully in Zoom
  - Help: ask for help at `queue.csc.kth.se`
  - Presentation: book a slot in Canvas - no help!
- Doing labs before the deadline - up to 3 pts on the exam

Grading of labs

- All labs can be done in **pairs**, but examined **individually.**
- A cumulative definition of grades:
  - E - Lab completed, but many written answers not correct.
  - D - Some written questions have not been answered correctly.
  - C - Minor difficulties in presenting lab results and responding to oral questions posed by TAs.
  - B - No difficulties in presenting lab results and responding to oral questions posed by TAs.
  - A - Is able to reason about questions beyond the scope of the lab.
- More detailed formal definition on the web page.
- Good idea: Present to each others for practice!

Lab procedure and requirements

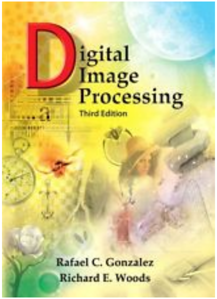
- What to do for each lab:
  - Book a slot for presentation in Canvas
  - Go through the lab instructions
  - Implement the required functions and run experiments
  - Answer the questions in the attached answer sheet
  - Upload (in a zip file) to Canvas
    1. All your code from the lab
    2. A Matlab script that steps through the lab
    3. Filled in answer sheet
  - Present your lab online using Zoom
- Start to work on labs as soon as possible!
- Think! What am I supposed to have learned?

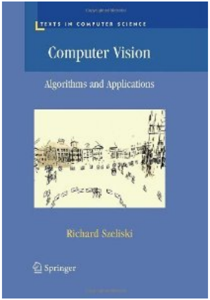
Quizzes for feedback

- Every week quizzes will be posted on Canvas
  - Should not take more than 10–15 minutes to complete
  - Quizzes are recommended, but not compulsory
- Quizzes provide feedback:
  - For you to test your degree of understanding
  - For me to know what to needs rehearsal
- Recommendation:
  - After each week, do the corresponding quiz
  - Before attending the exam, redo the quizzes
- Last year I saw a strong correlation between those doing the quizzes and those passing the exam

Course books

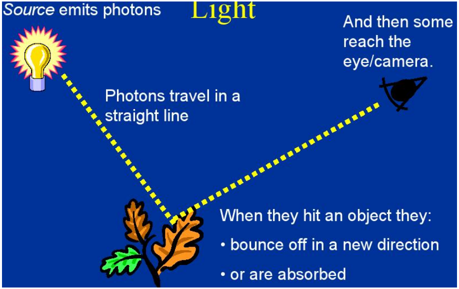
- R. Gonzalez and R. Woods: “Digital Image Processing”, Prentice Hall, 2008.
- R. Szeliski: “Computer Vision: Algorithms and Applications”, Springer, 2010. (available for free: http://szeliski.org/Book)





- Note: course books are used to help understanding, while assessment is based only on lecture and lab notes.

What does it mean to see?



- Vision is an active process for deriving efficient symbolic representations of the world from the light reflected from it.
- Computer vision: Computational models and algorithms to solve visual tasks and interact with the world.

Why is vision relevant?

Safety

Health

Security

Comfort

Fun

Access

There are many applications where vision is the only good solution.

Figure: Google self-driving cars

Figure: Tracking in 1000 Hz (Tokyo Uni)

Why is vision interesting?

- Intellectually interesting
  - How do we figure out what objects are and where they are?
  - Harder to go from 2D to 3D (vision), than from 3D to 2D (graphics).
- Psychology:
  - $\sim$ 50% of cerebral cortex is for vision.
  - Vision is (to a large extent) how we experience the world.
- Engineering:
  - Intelligent machines that interact with the environment.
  - Computer vision opens up for multi-disciplinary work.
  - Digital images are everywhere.

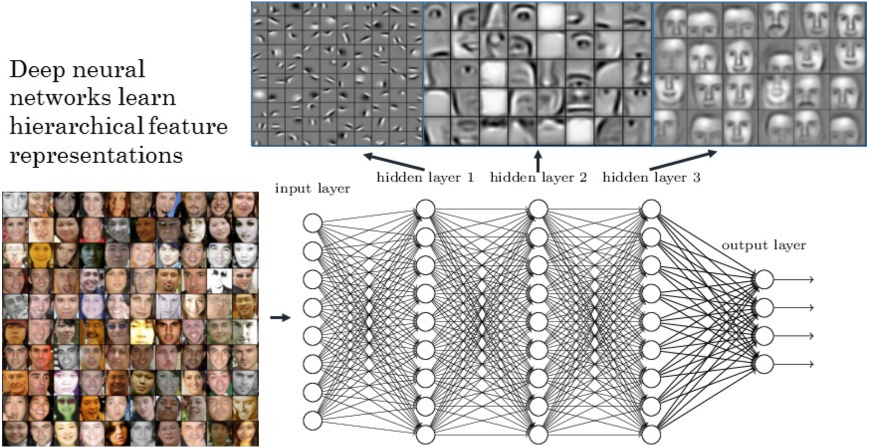
Multi-disciplinarity

- Neuroscience / Cognition: how do human beings do it?
- Philosophy: how to you e.g. define the concept of an object?
- Physics: how does an image become an image?
- Geometry: how do things look under different orientations?
- Signal processing: how do you work on images in practice?
- Statistics: deal with noise, develop appropriate models.
- Machine learning: how to draw conclusions from lots of data?

What about deep learning?

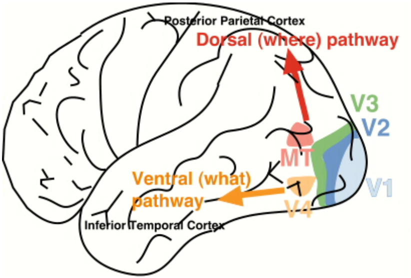
Why study computer vision, when we now have deep learning?

Deep neural networks learn hierarchical feature representations



What about deep learning?

Visual cortex with *what* and *where* pathways.

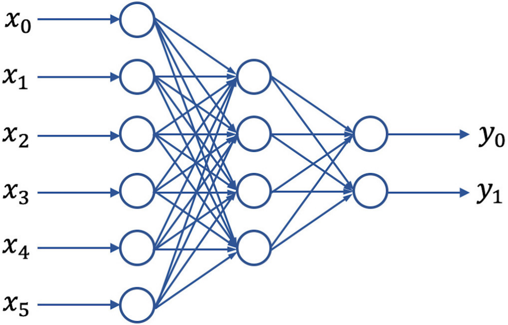


Deep learning can

- benefit from lots of data – but what if you don't have much data?
- answer *what*-questions – but not good at *where*-questions.

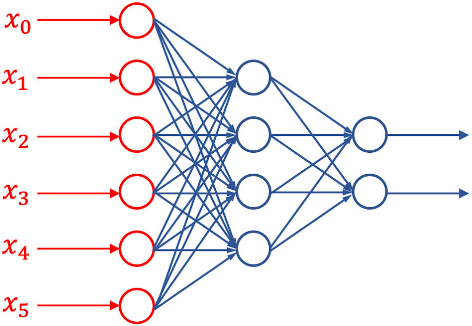
Computer vision is so much more than image classification.

Fully-connected neural networks (FCN)



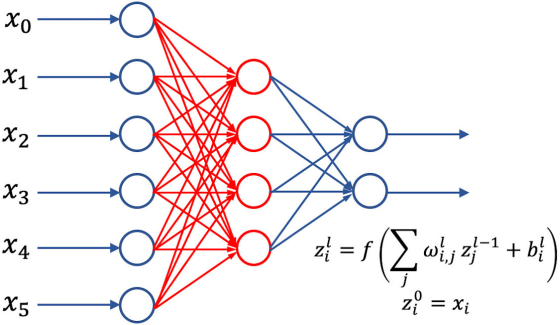
- Assume given: Many sets of training samples with matching inputs $\{x_0, ..., x_5\}$ and expected outputs $\{y_0, y_1\}$.

FCN training (forward pass)



- Take the input values of a particular training sample and set the input neurons z_i^0 to these values.

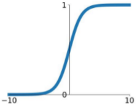
FCN training (forward pass)



- Compute a weighted sum of input neurons $z_j^0 = x_j$, add a bias b_i^0 and apply a non-linear activation function f.

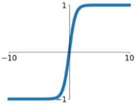
Sigmoid

$\sigma(x) = \frac{1}{1+e^{-x}}$



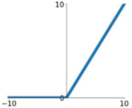
tanh

$\tanh(x)$



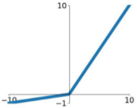
ReLU

$\max(0, x)$



Leaky ReLU

$\max(0.1x, x)$

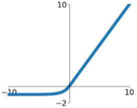


Maxout

$\max(w_1^T x + b_1, w_2^T x + b_2)$

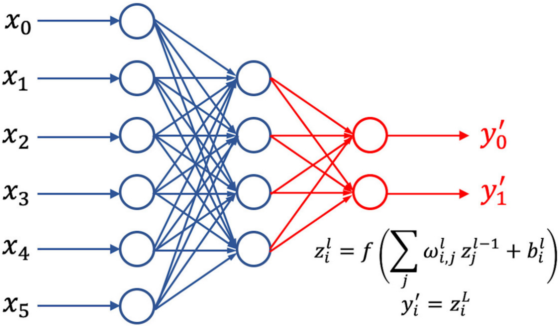
ELU

$$\begin{cases} x & x \geq 0 \\ \alpha(e^x - 1) & x < 0 \end{cases}$$



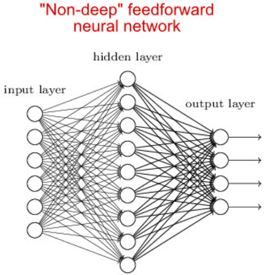
ReLU is the simplest function and is the most widely used.

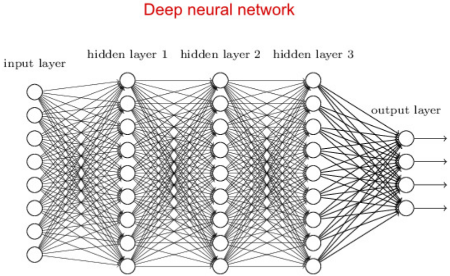
FCN training (forward pass)



- Compute the activation of the next layer neurons, which results in a predicted output $y_i' = z_i^L$.

Fully-connected neural networks (FCN)

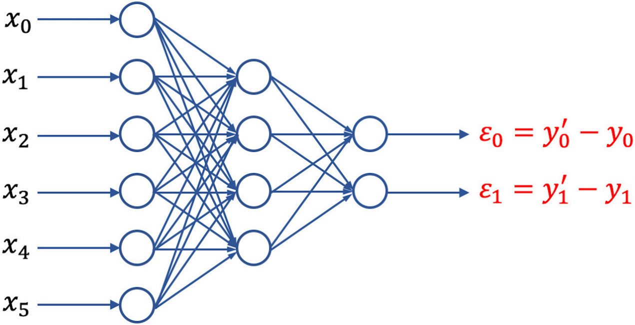




- Neurons on one layer depends on neurons from layer before

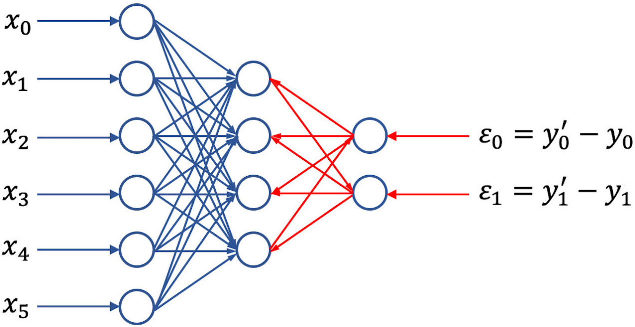
$$z_l = f\left(W_l z_{l-1} + b_l\right)$$

with hidden neurons z_n, input neurons $x = z_0$, output neurons $y = z_L$, weight matrix W_l, bias vector b_l, activation function f.



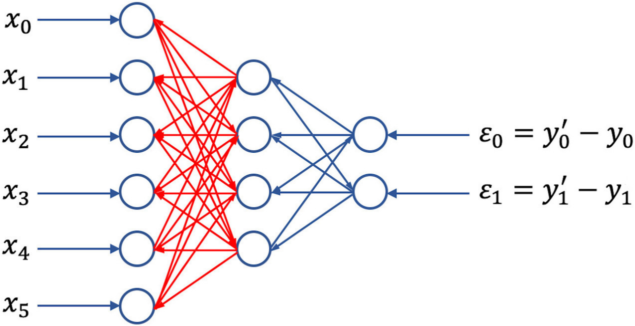
- Typically, there is an error ε_i, the difference between predicted y'_i and expected output y_i.

FCN training (backward pass)

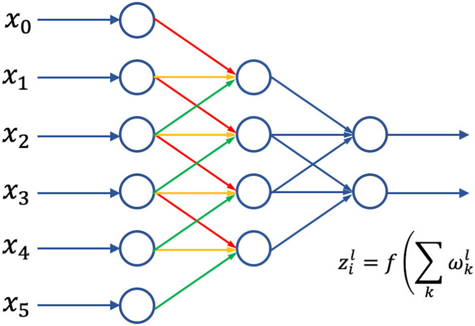


- Propagate the error ε_i backwards and adjust the weights $\omega^l_{i,j}$ and biases b^l_j along the way.

FCN training (backward pass)



- With gradient descent weights and biases are adjusted so that average errors will gradually decrease.
- Problem: with so many weights, this will take forever for data as large as images.



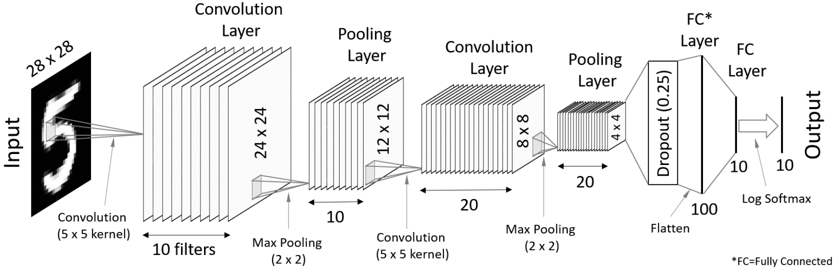
$$z_i^l = f\left(\sum_k \omega_k^l \, z_{i-k}^{l-1} + b_i^l\right)$$

Two important modifications:

- Weight sharing: use the same weight for all links of similar colour.
- Only connect to neurons in a local neighbourhood, not all neurons.

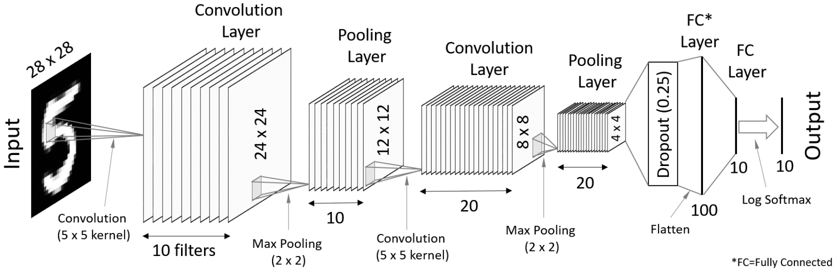
In this case: $3+1=4$ unknown parameters, instead of $6\times4+4=28$.

Convolutional neural networks (CNN)



- Instead of a large weight matrix, apply multiple small local filters
  Fewer parameters to learn $\Rightarrow$ easier to train for images
  ex. FCN: $28^4 = 614'656$, CNN: $5x5x10x20 = 5'000$ parameters
- Pooling: gradually reduce size by maximizing (or averaging) in small local windows
- Finish with fully-connected layers (like previous slides)

Convolutional neural networks (CNN)



- Convolution layers are based on convolutions

$$z_{n+1}^{c'} = f\left(\sum_c w_n^{c,c'} * z_n^c + b_n^{c'}\right)$$

  with filter kernels $w_n^{c,c'}$ and neurons z_n^c organized in channels c.
- More on convolutions will be covered in lecture 3.

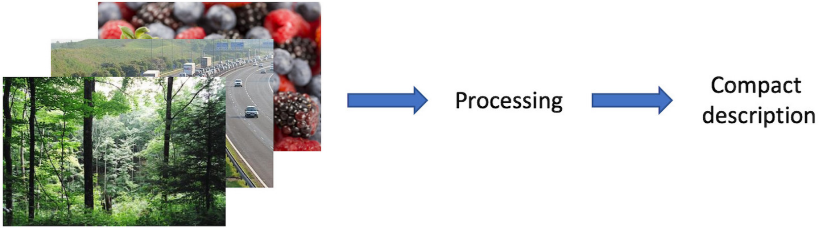
- The image is enhanced for easier interpretation.
- Different levels of processing (often used as pre-processing).

Purpose of image processing

- Enhance important image structures
- Suppress disturbances (irrelevant info, noise)
- Examples: Poor image data in medicine, astronomy, surveillance.

Subjects treated in this course:

- Image sampling, digital geometry
- Enhancement: gray scale transformation (histogram equalization), spatial filtering (reconstruction), morphology
- Linear filter theory, the sampling theorem

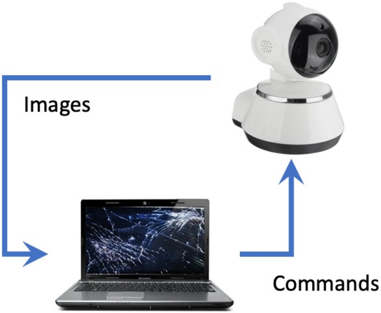


- Purpose: Generate a useful compact description of the image

Subjects studied in this course:

- Feature detection and matching
- Object and image segmentation
- Recognition and classification

Computer vision



- Purpose: Achieve an understanding of the world, possibly under active control of the image acquisition process.
- Examples: object tracking, robot motion control
- The whole field often called computer vision (incl. image analysis)

Computer vision examples

Figure: Scene parsing (Hong Kong)

Computer vision examples

Figure: OpenPose: Multi-person tracking (CMU)

$<$ Underdetermined 2D $\rightarrow$ 3D problem $>$

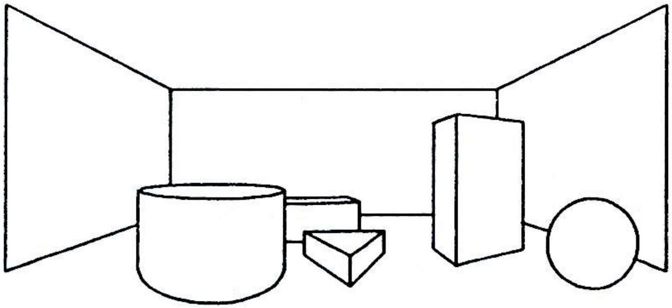
Main assumptions:

- The world we observe is constructed from coherent matter.
- We can therefore perceive it as constructed from smooth surfaces separated by discontinuities.

The importance of discontinuities: A discontinuity in image brightness may correspond to a discontinuity in either

- Depth changes
- Surface orientation
- Surface structure
- Illumination changes

What are the explanations for the discontinuies you see?

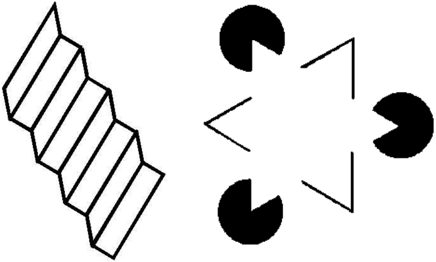


Vision is an active process!

- Active:
  - In nature seeing is always (?) associated with acting.
  - Acting can simplify seeing, e.g. move your head around an object.
  - A computer vision system may control its sensory parameters, e.g. viewing direction, focus and zoom.
- Process:
  - No "final solution". Perception is a result of continuous hypothesis generation and verification.
  - Vision is not performed in isolation, it is related to task and behaviors.

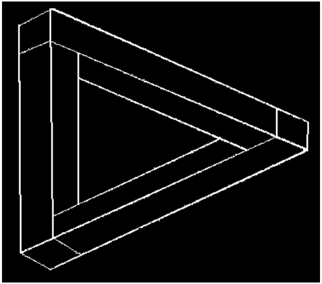
Human vision is not perfect!

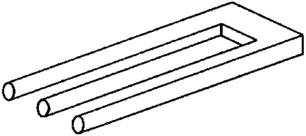
Reversing staircase illusion and subjective contours:



- Our perceptual organization process continues after providing a (first) interpretation. Continue viewing the reversing staircase illusion and you will see it flip into a second staircase.

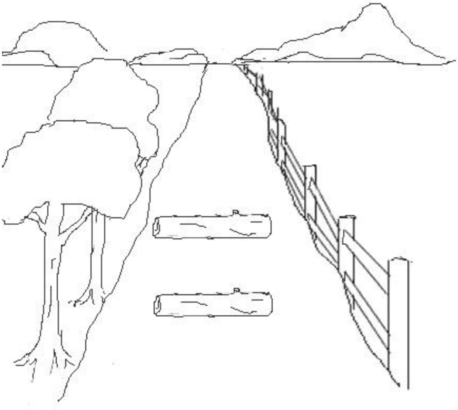
Impossible objects





Another example that vision is an ongoing process.

Depth illusion - size constancy



We tend to “normalize” things, such as size, shape and colors.

Depth illusion - size constancy

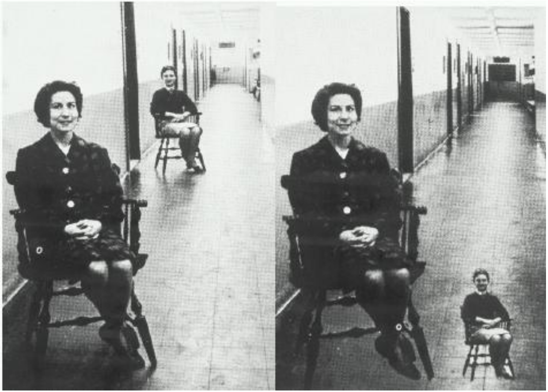
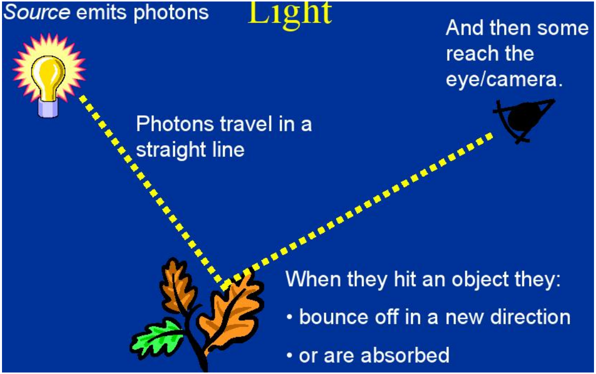
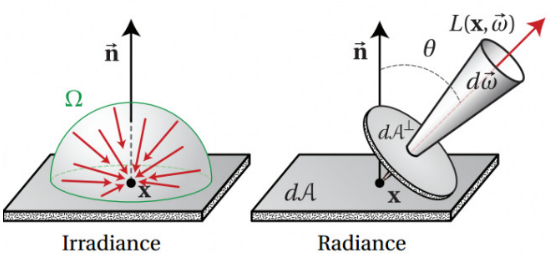


Image formation is a physical process that captures scene illumination through a lens system and relates the measured energy to a signal.

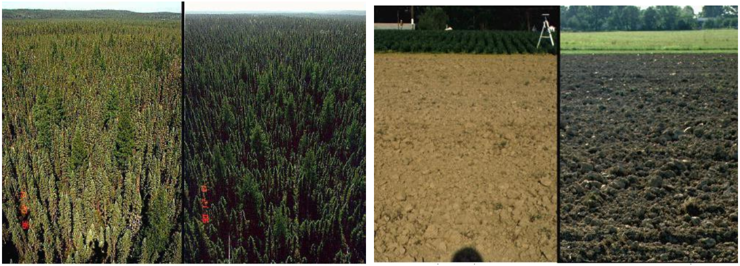


Basic concepts

- Irradiance E: Amount of light falling on a surface, in power per unit area (watts per square meter).
- Radiance L: Amount of light radiated from a surface, in power per unit area per unit solid angle. Informally "Brightness".



- Image irradiance E is proportional to scene radiance

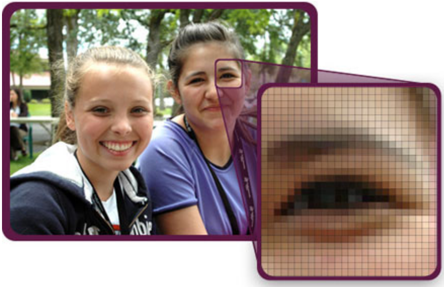


Left: Forest image (left): sun behind observer, (right): sun opposite observer
Right: Field with rough surface (left): sun behind observer, (right): sun opposite observer.

Digital imaging

Image irradiance E $\times$ area $\times$ exposure time $\rightarrow$ Intensity

- Sensors read the light intensity that may be filtered through color filters, and digital memory devices store the digital image information either as RGB color space or as raw data.
- An image is discretized: sampled on a discrete 2D grid $\rightarrow$ array of color values.



Imaging acqusition - From world point to pixel

- World points are projected onto a camera sensor chip.
- Camera sensors sample the irradiance to compute energy values.
- Positions in camera coordinates (in mm) are converted to image coordinates (in pixels) based on the intrinsic parameters of the camera:

  - size of each sensor element,

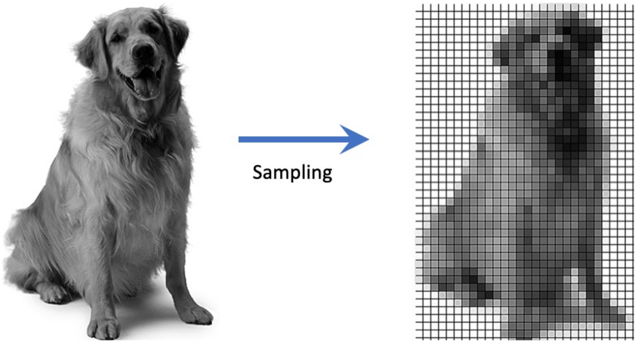
  - aspect ratio of the sensor (xsize/ysize),

  - number of sensor elements in total,

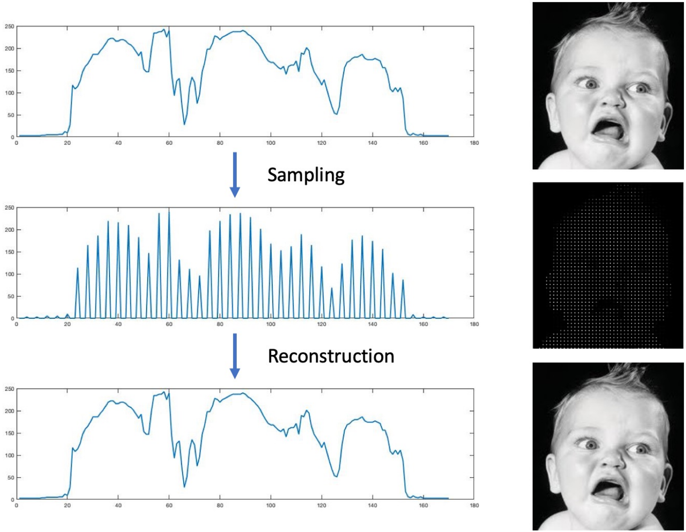
  - image center of sensor chip relative to the lens system.

Sampling and quantization

- Sample the continuous signal at a finite set of points and quantize the registered values into a finite number of levels.
- Sampling distances $\Delta x, \Delta y$ and Δt determine how rapid spatial and temporal variations can be captured.



Sampling and quantization

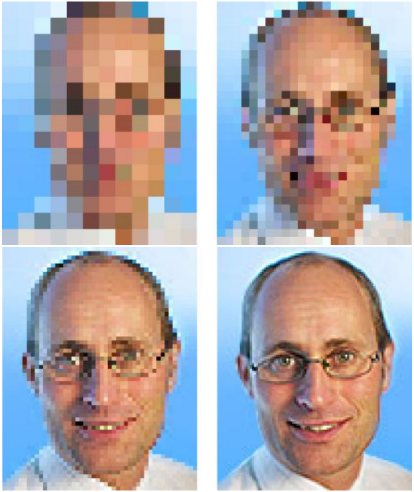


If sampling rate is high enough. original image can (at least in theory) be perfectly reconstructed.

Sampling and quantization

- Quantization: Assigning integer values to pixels (sampling an amplitude of a function).
- Quantization error: Difference between the real value and assigned one.
- Saturation: When the physical value moves outside the allocated range, then it is represented by the end of range value.

Different image resolutions



Sampling due to limited spatial and temporal resolution.

Quantization due to limited intensity resolution.

Summary of good questions

- What is computer vision good for?
- In what ways is computer vision multi-disciplinary?
- In what sense is vision is an underdetermined inverse problem?
- What is image processing, image analysis and computer vision?
- Why are discontinuities so important in vision?
- What could a possible vision system consist of?
- Why is vision an active process?
- What parameters affects the quality in the acquisition process?
- What is sampling and quantization?

Recommended readings

- Gonzalez and Woods: Chapters 1.1 - 1.4
- Szeliski: Chapters 1.1 - 1.2
- Introduction to labs (on web page)