Image Processing and Computer Vision

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www.mia.uni-saarland.de/Teaching/ipcv07.shtml

Organisatorial Issues

Welcome to this class!
Please do not hesitate to pose questions (in English or German).

Why is this Class Important?

- broad introduction into mathematically well-founded areas of image processing and computer vision
- important in numerous applications, e.g. medical imaging, computer-aided quality control, robotics, computer graphics, bioinformatics, multimedia and artificial intelligence.
- nice application area for almost all branches of mathematics
- qualify for starting a bachelor's thesis in our group

Organisatorial Issues (2)

How Can I Make Use of These Classes?

- 4 hours classroom lectures, 2 hours tutorials (9 ECTS points)
- can be used in numerous study programmes:
  - **Visual Computing:**
    – class in the core area visual computing / subarea image analysis
  - **Computer Science:**
    – (theoretical) core class (Theorie-Stammvorlesung)
    – applied mathematics class if your minor is mathematics
  - **Mathematics:**
    – applied mathematics class
    – computer science class if your minor is computer science
  - **Computers and Communications:**
    – master core lecture
  - **Bioinformatics:**
    – as core lecture

Organisatorial Issues (3)

What Prerequisites are Required?

- undergraduate mathematics (e.g. Mathematik für Informatiker I–III)
- elementary C knowledge (for the programming assignments)
- passive knowledge of English
  (solutions in assigments or exam can be submitted in German)

Tutorials

- theoretical and programming assignments, alternating each week
- coordinated by Dr. Andrés Bruhn
- Tutors: Thomas Bühler, Oliver Demetz, Luis Pizarro, Sebastian Zimmer.
- 6 groups, 4 time slots: Tue + Wed, 2–4 pm, 4–6 pm
  (1 German group, 1 group for honour's programme: Tue 4–6 pm)
- start: next week

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Grading Policy

- Written exam: Friday, February 29, 2008 from 2:00 to 5:00 pm.
  Second chance: Wednesday, April 9, 2008 from 2:00 to 5:00 pm.
  You can take the lecture notes and the tutorial notes with you, but no books.
  The better grade counts.

- In order to qualify for both exams you need 50 % of all points from the assignments. Theoretical and practical assignments count for the final score.

- Working in groups of up to 3 people is permitted, but they must be in the same tutorial group.

Registration and Lecture Notes

- Please register for tutorials between Tue, Oct. 23, 3 pm and Fri, Oct. 26, 3 pm:

  `www.mia.uni-saarland.de/Teaching/ipcv07.shtml`

- You can also download the lecture notes from there (password-protected).

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Important Areas within Visual Computing

- **Image Processing (Bildverarbeitung):**

  A digital image is transformed into another digital image, that allows a better interpretation by humans or computers

  Example: Denoising

- **Computer Vision, Image Understanding (Rechnersehen, Bildverstehen):**

  Extraction of information about the 3-D world from 2-D images.

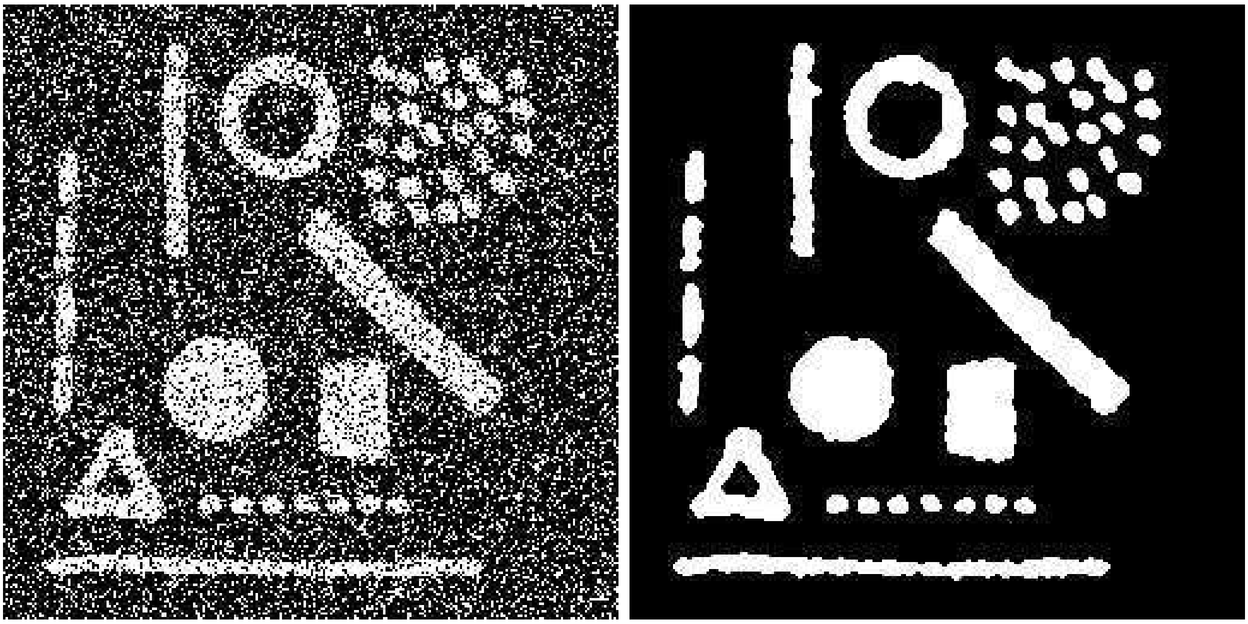
  Example: Stereographic reconstruction

- **Pattern Recognition (Mustererkennung):**

  Labelling of image structures to certain classes.

  Examples: Character recognition, cell classification

Important Areas within Visual Computing (2)



Example for an image processing application. **(a) Left:** Noisy original image. **(b) Right:** Filtered. Author: J. Weickert (1999).

Important Areas within Visual Computing (3)

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Example for a computer vision application. **(a) Left:** Stereo image pair. **(b) Right:** 3-D reconstruction. Authors: L. Alvarez, R. Deriche, J. Sánchez, J. Weickert (2002).

Important Areas within Visual Computing (4)

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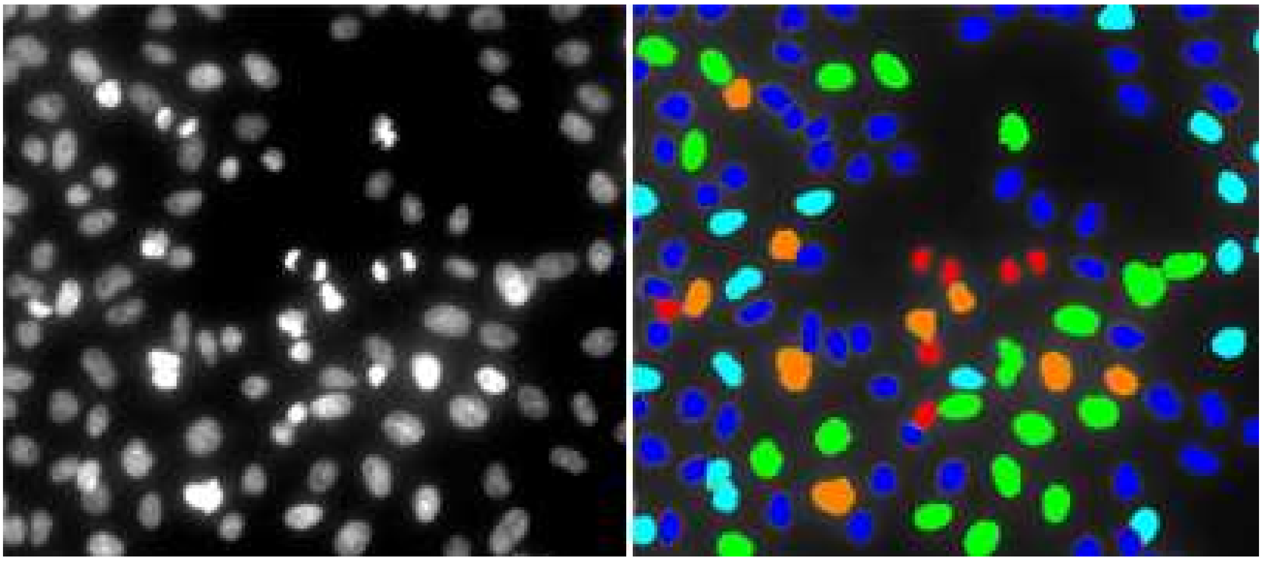

Example for a pattern recognition application. **(a) Left:** Cells. **(b) Right:** Classification into different cell cycle phases. Source: MetaMorph Analysis, `http://www.moleculardevices.com/`.

Important Areas within Visual Computing (5)

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- **Computer Graphics (Computergrafik):**

  Synthesis of a digital image that is supposed to look like a (usually realistic) image of a 3-D scene.

  Example: Computer games

- **Geometric Modelling (Geometrische Modellierung):**

  Mathematical description of curves and surfaces for synthesising 2-D and 3-D objects on a computer

  Example: CAD-based design of a car coachwork

- **Imaging (Bildgebende Verfahren):**

  deals with all aspects of image creation

  Example: Tomographic reconstruction

Important Areas within Visual Computing (6)

Example for a computer graphics application: Realistically looking simulation of a forest using ray tracing. Author: P. Slusallek.

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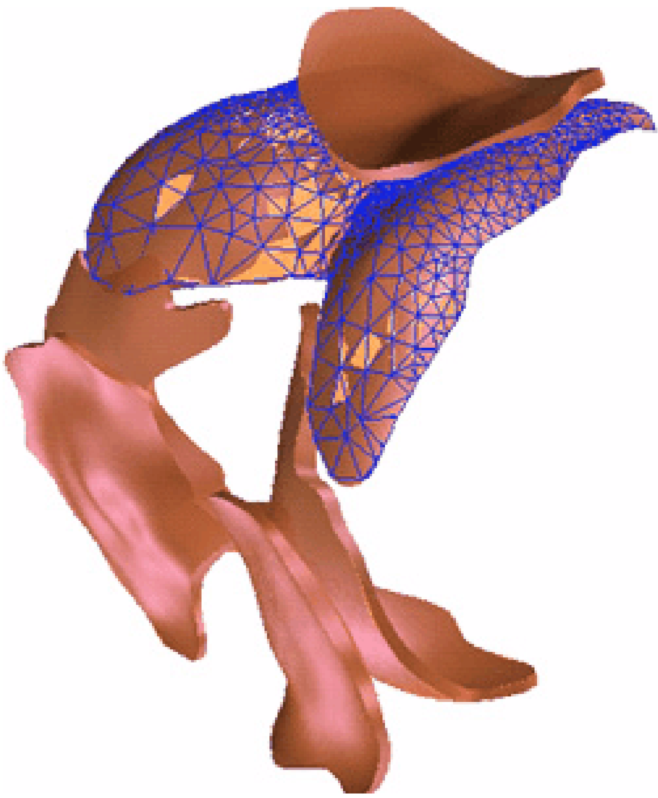
Important Areas within Visual Computing (7)



Example for a geometric modelling application: A model of a tissue in a human knee. Source: `http://www.scorec.rpi.edu/research_biomechanical.html`.

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Important Areas within Visual Computing (8)

Example for an imaging application: Magnetic resonance image of a mouse embryo. Author: F. Volke.

Important Areas within Visual Computing (9)

Collective Terms

- **Image Analysis (Bildanalyse):**

  includes image processing, computer vision, pattern recognition

- **Image Synthesis (Bildsynthese):**

  includes computer graphics and geometric modelling

- **Visual Computing (Computervisualistik):**

  comprises everything related to imaging and the analysis and synthesis of digital images

This class focuses on image analysis, in particular on image processing and computer vision.
There is a growing confluence between image analysis and synthesis. In problems such as human motion capturing they even appear simultaneously.

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Planned Contents (1)

Planned Contents

1. **Basics**
   - 1.1 Image Types and Discretisation
   - 1.2 Degradations in Digital Images
2. **Image Transformations**
   - 2.1 Fourier Transform
   - 2.2 Image Pyramids
   - 2.3 Wavelet Transform
3. **Colour Perception and Colour Spaces**
4. **Image Compression**
5. **Image Interpolation**
6. **Image Enhancement**
   - 6.1 Point Operations
   - 6.2 Linear Filtering
   - 6.3 Wavelet Shrinkage, Median Filtering, M-Smoothers
   - 6.4 Mathematical Morphology
   - 6.5 Diffusion Filtering
   - 6.6 Variational Methods
   - 6.7 Deblurring

Planned Contents (2)

7. **Feature Extraction**
   - 7.1 Edges
   - 7.2 Corners
   - 7.3 Lines and Circles
8. **Texture Analysis**
9. **Segmentation**
   - 9.1 Classical Methods
   - 9.2 Variational Methods
10. **Image Sequence Analysis**
    - 10.1 Local Methods
    - 10.2 Variational Methods
11. **3-D Reconstruction**
    - 11.1 Camera Geometry
    - 11.2 Stereo
    - 11.3 Shape-from-Shading
12. **Object Recognition**
    - 11.1 PCA Methods
    - 11.2 Invariances

References

We do **not** focus on a specific textbook:
Our didactic concept differs from all of them.
However, here are some of the more useful books:

Textbooks on Image Processing

- J. Bigun: *Vision with Direction*. Springer, Berlin, 2006.
  One of most systematic books on image processing, with a clear focus on matrix representations. My favourite book on image processing.
- R. C. Gonzalez, R. E. Woods: *Digital Image Processing*. Addison-Wesley, Reading, Second Edition, 2002.
  A classical book on image processing. Comprehensive and fairly well readable.
- K. D. Tönnies: *Grundlagen der Bildverarbeitung*. Pearson Studium, München, 2005.
  One of the better German books on image processing. Contains no computer vision.

Textbooks on Computer Vision

- E. Trucco, A. Verri: *Introductory Techniques for 3-D Computer Vision*. Prentice-Hall, Upper Saddle River, 1998.
  Good selection of important aspects.
- R. Jain, R. Kasturi, B. G. Schunck: *Machine Vision*. McGraw-Hill, New York, 1995.
  Simple introduction to computer vision (and a bit of image processing), but sometimes too simple.
- R. Klette, K. Schlüns, A. Koschan: *Computer Vision: Three-Dimensional Data from Images*. Springer, Singapore, 1998.
  Good for 3-D reconstruction (stereo, shape-from-shading).

Useful Internet Resources

- **CV Online**
  http://homepages.inf.ed.ac.uk/rbf/CVonline/
  Online compendium on numerous image processing and computer vision topics.
  Often very useful.

- **Computer Vision Homepage**
  http://www-cgi.cs.cmu.edu/afs/cs/project/cil/ftp/html/vision.html
  useful links for many computer vision problems, but needs some update

- **Keith Price's Annotated Computer Vision Bibliography**
  http://iris.usc.edu/Vision-Notes/bibliography/contents.html
  excellent, when searching for specific references

- **CiteSeer**
  http://citeseer.ist.psu.edu/cs
  numerous citations and online articles in all areas of computer science

Lecture 1:
Image Types and Discretisation

Contents

Sampling and Quantisation

Continuous Greyscale Image (Kontinuierliches Grauwertbild):

- mapping f from a rectangluar domain (Definitionsbereich) $\Omega = (0, a_1) \times (0, a_2)$ to a co-domain (Wertebereich) $\mathbb{R}$:

$$f: \; \mathbb{R}^2 \supset \Omega \; \rightarrow \; \mathbb{R}$$

- domain Ω is called *image domain* or *image plane*
- co-domain specifies *grey value*
- Usually low grey values are dark and high grey values bright.

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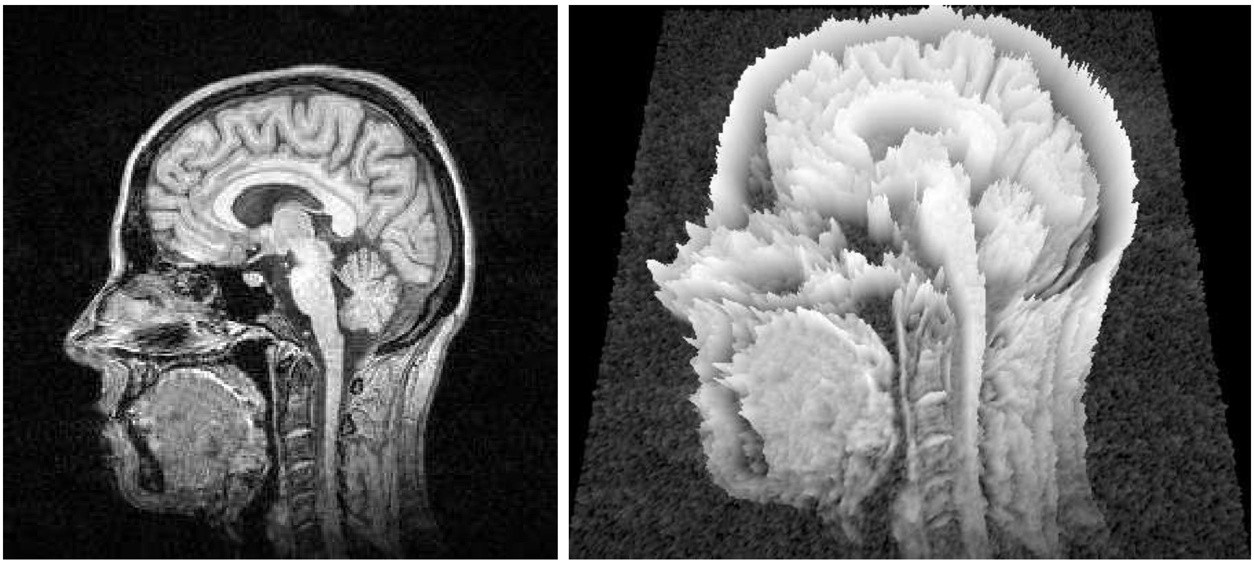


(a) Left: Magnetic resonance (MR) image of a human head. **(b) Right:** Representation as a function $f(x, y)$ over a rectangular image domain Ω. Authors: J. Weickert, C. Schnörr (2000).

Sampling and Quantisation (3)

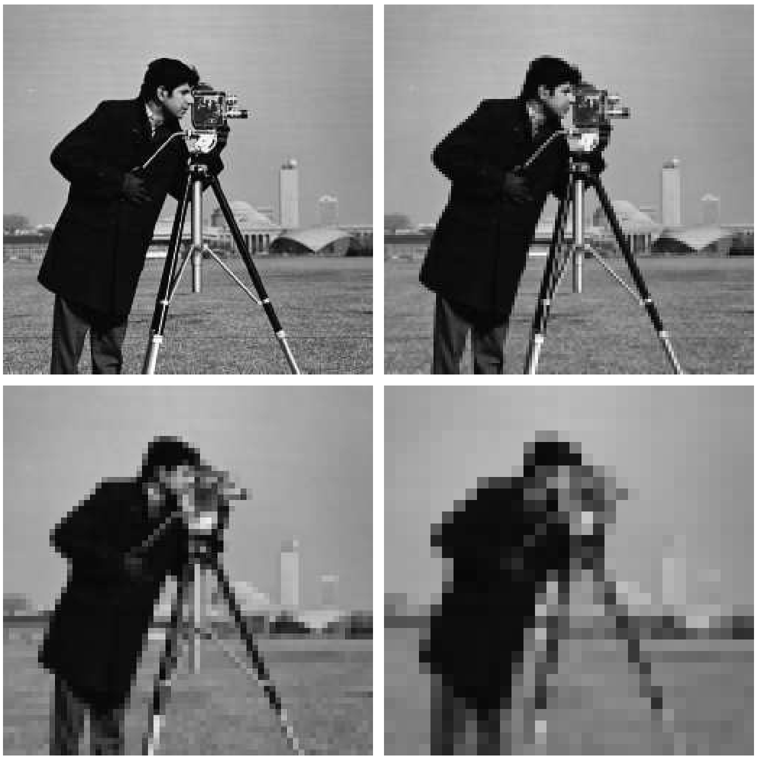
Sampling:

- discretisation of the *domain* Ω
- Image data are only given on a rectangular point grid within the image domain Ω.
- creates a digital image

$$\{f_{i,j} \mid i = 1, ..., N;\ j = 1, ..., M\}$$

- The grid point / cell (i, j) is called *pixel* (picture element).
- 2-D images usually have equal pixel distances in both directions.
- Image processing people often normalise these grid sizes to 1.
- If the sampling rate is too low, the image quality degrades severely.

Sampling and Quantisation (4)



Digital test image with different sampling rates. **(a) Top left:** Sampled with 256×256 pixels. **(b) Top right:** 128×128 pixels. **(c) Bottom left:** 64×64 pixels. **(d) Bottom right:** 32×32 pixels. Author: J. Weickert (2000).

Quantisation (Quantisierung):

- discretisation of the *co-domain*
- saves disk space
- if a grey values is coded by a single byte, the discrete co-domain is given by $\{0, 1, ..., 255\}$
- Binary images have the co-domain $\{0, 1\}$.
- Humans can distinguish only 40 greyscales.
  They are even very good in recognising the content of binary images.

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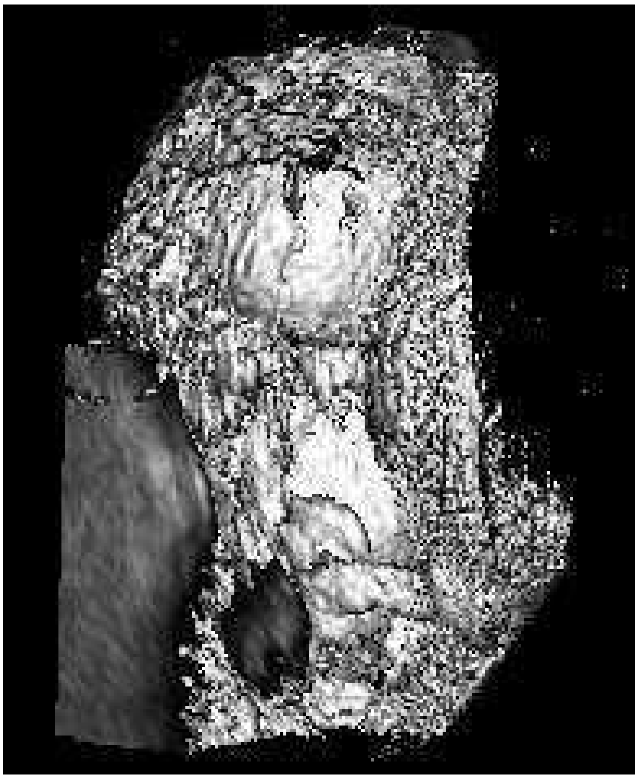
Digital test image (256×256 pixels) with different quantisation rates. **(a) Top left:** 256 greyscales. **(b) Top right:** 32 greyscales. **(c) Bottom left:** 8 greyscales. **(d) Bottom right:** 2 greyscales. Author: J. Weickert (2000).

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

Types of Images

m-Dimensional Images

- domain in $\mathbb{R}^m$
- $m = 1$: signals
- $m = 2$: (two-dimensional) images
- $m = 3$: three-dimensional images
  - important in medical imaging, e.g. computerised tomography (CT, Computertomographie), magnetic resonance imaging (MRI, Kernspintomographie).
  - image points/cells in 3-D are called *voxels* (volume elements).
  - voxel dimensions usually differ in different directions!



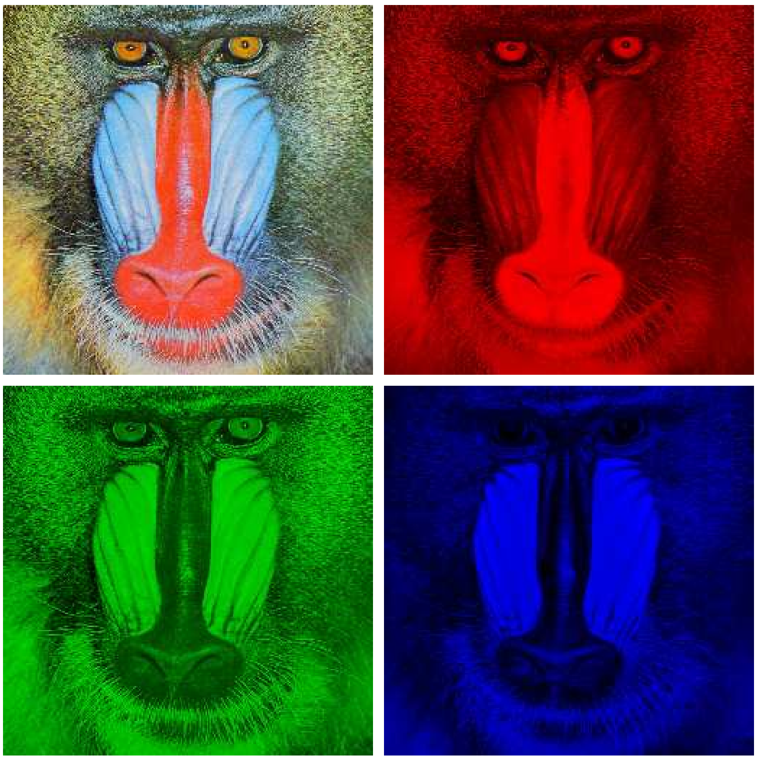
Rendering of a 3-D ultrasound image of a human fetus in its 10th week. Authors: J. Weickert, K. Zuiderveld, B.M. ter Haar Romeny, W. Niessen (1997).

Types of Images (3)

Vector-Valued Images

- co-domain in $\mathbb{R}^n$, containing n channels
- Example 1: Colour images
  Three channels: R (red), G (green), B (blue).
  Humans can distinguish 2,000,000 colours!
- Example 2: Multispectral image (e.g. satellite images)
  numerous channels (4–30) that represent different frequency bands

Types of Images (4)



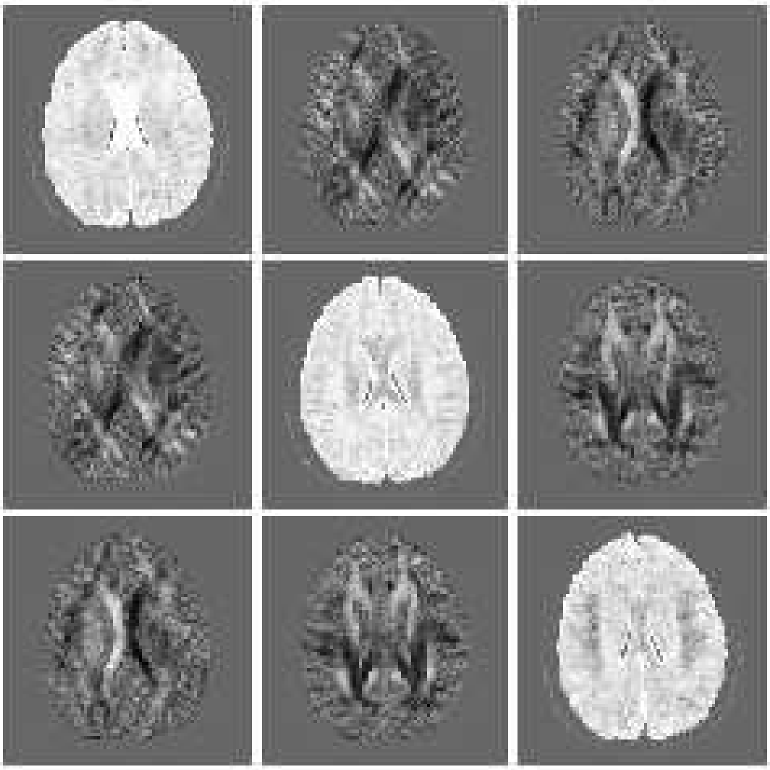
Colour image as example for a vector-valued image. **(a) Top left:** Original image. **(b) Top right:** Red channel. **(c) Bottom left:** Green channel. **(d) Bottom right:** Blue channel. Author: J. Weickert (2000).

Types of Images (5)

Matrix-Valued Images

- co-domain in $\mathbb{R}^{n \times n}$
- Example: diffusion tensor MRI (DT-MRI, Diffusionstensor-Kernspintomographie): measures in each voxel of a 3-D image domain a symmetric positive definite 3×3 matrix
- may create additional constraints, e.g.:
  A reasonable filter should not destroy relevant properties such as positive definiteness of the matrix field.

Types of Images (6)



Images of the nine coefficients of a DT-MRI data set. Since the diffusion matrix is a symmetric 3×3 matrix, only 6 out of 9 images differ. Authors: D. Weinstein, G. Kindlmann, E. Lundberg (1999).

Types of Images (7)

Image Sequences (Bildfolgen)

- One can consider image squences for any of the above mentioned types of images.
- This increases the dimensionality of the domain from m to $m + 1$.
- Example: 3-D echo cardiography (Echokardiographie)
  creates a sequence of 3-D scalar-valued images (can be regarded as 4-D image)

Relevant Images in This Class

- We mainly focus on 2-D scalar images and their image sequences.
- Many methods can be generalised to other types of images.

Types of Images (8)

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Form left to right and from top to bottom: Four subsequent frames of an image sequence (the famous Hamburg taxi scene, 256×190 pixels). Can you recognise what has moved in which direction? Source: `http://i21www.ira.uka.de/image_sequences/`

Summary

- Digital images have a discrete domain (sampling) and a discrete co-domain (quantisation)
- generalisation of the domain:
  m-dimensional images, image sequences
- generalisation of the co-domain:
  vector-valued images, matrix-valued images