Introduction to Image Acquisition Methods

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www.mia.uni-saarland.de/Teaching/iam07.shtml

Motivation and Formalia

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

Goal of This Class

- This lecture is intended as a supplement to classes in image processing such as
  - *Image Processing and Computer Vision*
    (offered this semester)
  - *Differential Equations in Image Processing and Computer Vision*
    (offered usually in summer terms)
- You can attend it independently on whether you already have attended, are currently attending or still plan to attend any image processing classes.

Motivation and Formalia (2)

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How Can I Make Use of These Classes?

- 2 hours classroom lectures, no tutorials
- can be used in different study programmes:
  - **Visual Computing:**
    - ∗ class in the core area visual computing, subarea image aquision and geometric foundations (4 ECTS points)
  - **Computer Science:**
    - ∗ advanced class (Vertiefungsvorlesung, 4 ECTS points)
    - ∗ applied mathematics class if your minor is mathematics (3 ECTS points)
  - **Mathematics:**
    - ∗ applied mathematics class (3 ECTS points)
    - ∗ computer science class if your minor is computer science (4 ECTS points)

Motivation and Formalia (3)

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What Prerequisites are Required?

- undergraduate mathematics (e.g. Mathematik für Informatiker I–III)
- passive knowledge of English (exam questions available in English and in German)
- knowledge in image processing or physics helpful, but not required

Grading Policy

- Written exam: Wednesday, February 27, 2008
  Second chance: Thursday, April 10, 2008
  The better grade counts.

Registration and Lecture Notes

- Please register at `www.mia.uni-saarland.de/Teaching/iam07.shtml`.
- You can also download the lecture notes from there (password-protected).

What is This All About?

- In image processing courses, you learn how to denoise or enhance images. But:

  What do the images mean?

  Which method is appropriate for a given image?

  The answers are related, and depend on how images emerge.

- Our goal in this course is therefore to understand how images are generated and what they mean.

- We will discuss a broad range of image acquisition methods, whose applications vary widely, including e.g.
  - everyday photography
  - medical imaging
  - planetary remote sensing
  - astronomy
  - quality inspection.

References

- The course does *not* follow a specific book.

- The following books cover many of its topics (see library):
  - S. Webb:
    The Physics of Medical Imaging.
    Institute of Physics Publishing, Bristol 1988.
  - C. Epstein:
    The Mathematics of Medical Imaging.
    Pearson, Upper Saddle River 2003.
  - R. Blahut:
    Theory of Remote Image Formation.
    Cambridge University Press, 2005.
  - B. Jähne, H. Haußecker, P. Geißler (Eds.):
    Handbook of Computer Vision and Its Applications.
    Volume 1: Sensors and Imaging.
    Academic Press, San Diego 1999.

- Further references will be given where appropriate.

Lecture 1:

Introduction and Basic Concepts

Contents

- Introductory Examples
- Basic Notions
- Discretisation of Image Domain and Range
- Image Acquisition and Transmission Medium
- Overview of Forthcoming Topics

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Introductory Examples

Early analog photograph (so-called *Daguerreotype*) acquired using visible light (American woman, ca. 1858. – *Library of Congress, public domain. Copied from www.kefk.net.).*

Introductory Examples (2)

Digital photograph acquired using visible light (Schlösschen Schönburg near Hofgeismar, Germany).

Introductory Examples (3)

Analog radiography images generated by X-ray transmission. **Left:** Human foot in two positions. **Right:** Human vertebra seen from the side (partial view).

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Introductory Examples (4)

Magnetic resonance image of a human head.

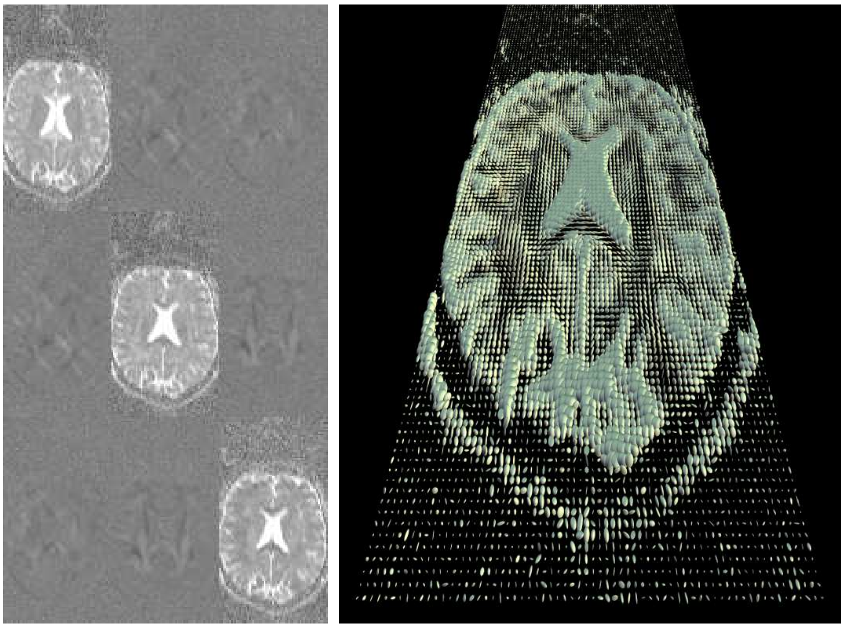
Introductory Examples (5)

Ultrasound image of a renal transplant *(Plenum Press Publishers/Albert and Pandit 1999)*.

Introductory Examples (6)

Ultrasound image of a human embryo.

Introductory Examples (7)



Diffusion tensor magnetic resonance image of a human head (one slice). In each voxel, a *diffusion tensor* is measured, i.e. a symmetric 3×3 matrix that indicates "mobility" of water molecules in different directions within tissue. Such images are useful in studying fibres and connectivity in the brain. **Left:** Matrix entries represented in tiles of a grey-value image. **Right:** Matrices are represented by ellipsoids. *(Image data: Oliver Gruber, Thomas Kamer et al., University Hospital of Saarland University, Homburg.)*

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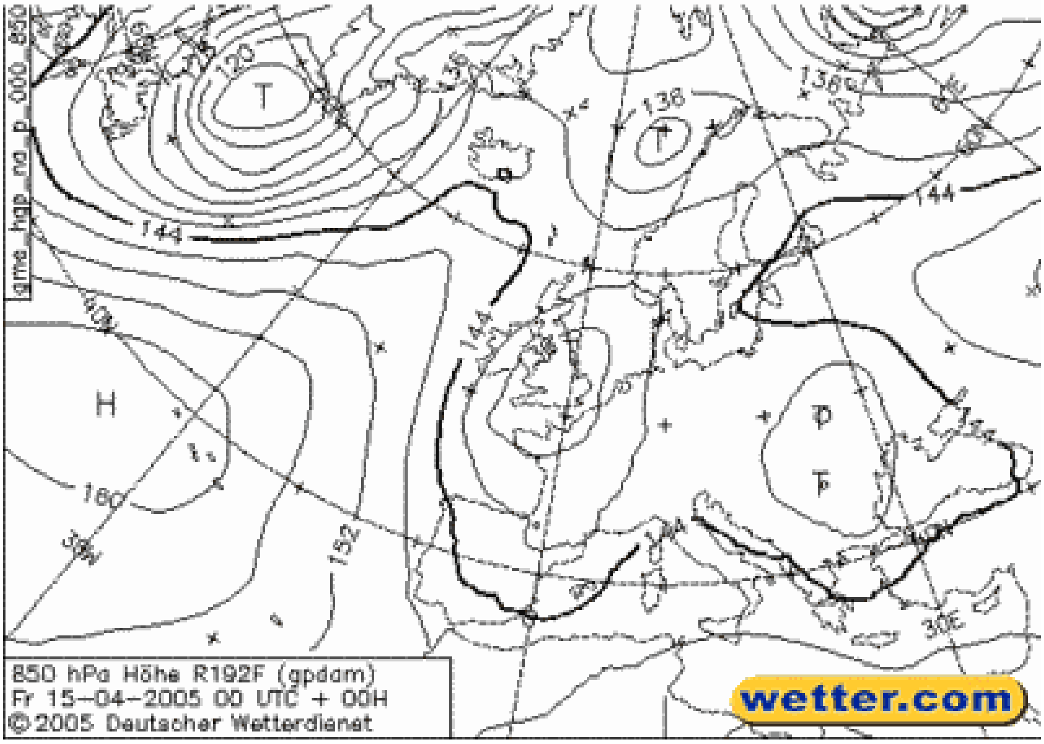
Introductory Examples (8)



Map of atmospheric pressure. Even such a map can be viewed as an image: The pressure value in each point would be the value, not the drawn lines and digits. *(Deutscher Wetterdienst.)*

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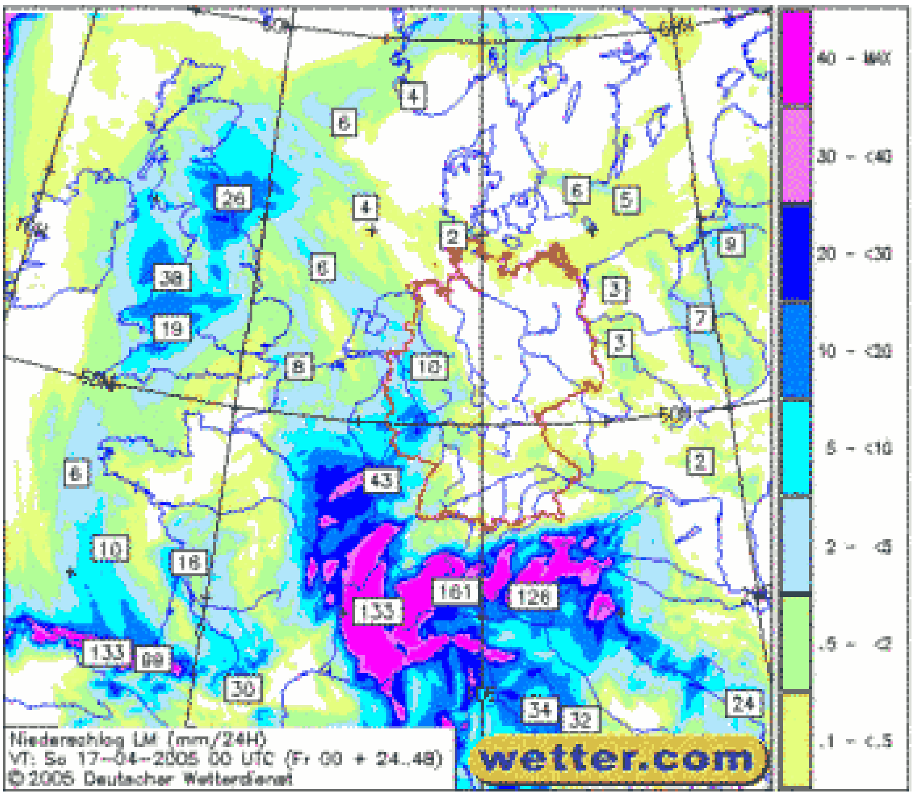
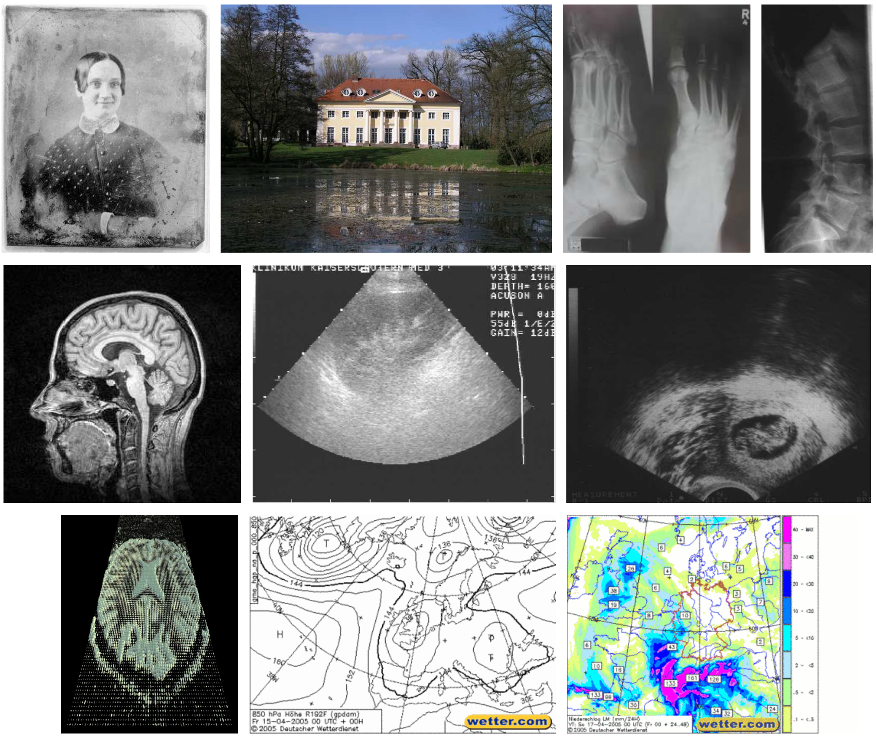
Introductory Examples (9)



Rainfall map. *(Deutscher Wetterdienst.)*

Basic Notions



What do all these images have in common?

Definitions

- *image:* spatial arrangement of measured data of uniform type
- *object:* physical property varying in space that is to be represented by the image
- *image acquisition:* process of measuring the data belonging to an image
- *image sensor:* measuring instrument that generates the image

Sender–Receiver Model

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Transmission Channel, Direct Versus Remote Image Acquisition

- Occasionally, image data can be measured directly (such as atmospheric pressure maps). This is called *direct image acquisition*.

  Only in this case, the transmission channel in the sender–receiver model consists just of the sensor.

- However, in most important cases, we adopt the view that images depict objects which are not at the same location as the image sensors. We call this *remote image acquisition.*

  In this case, the transmission channel involves some *medium*, typically some sort of radiation or waves.

In this lecture, the medium of transmission is a main criterion for the systematisation of image acquisition methods.

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Discretisation of Image Domain and Range

Object and Image as Functions

- In mathematical formalism, the object is a function

$$f: \quad \Omega_{\text{phys}} \to R_{\text{phys}}.$$

  Ω_{phys}: some domain of physical space (or space-time)
  R_{phys}: co-domain; the range of values of the physical quantity

- The measured image is also a function

$$g: \quad \Omega \to R.$$

  Ω: *image domain* – some subset of the plane (or space)
  R: *range* – some set of admissible values

- Neither Ω nor R are identical with their "objective" (physical) counterparts. The transformations from Ω_{phys} to Ω and R_{phys} to R are part of the transmission channel.

Discretisation of Image Domain and Range (2)

Sampling

- Primarily, the object domain Ω_{phys} is thought of as a continuous domain in plane (2-D) or space (3-D).
- The domain Ω of a digital image is discrete (since only finitely many values can be measured and stored).
- *Sampling* denotes the process of reducing the continuous object domain to the discrete image domain.
- Typical choices for Ω:
  - *regular grid in space:* The data locations are arranged equally spaced in two or three dimensions. The data structure is naturally represented by an array.
  - *regular grid in space and time:* For time-variant images, time is added as an additional dimension and also sampled in equal intervals. In this case one speaks of an *image sequence*.
  - *irregular grids:* Irregular arrangements of sampling points are possible in special applications.

Discretisation of Image Domain and Range (3)

- Simplifying assumption sometimes used: $\Omega \subset \Omega_{\text{phys}}$, i.e. we know exactly where the sampling points are located in physical space.
  Not always true: For instance, when photographing a 3-D scene, resulting in a 2-D image, this is no bijective mapping.
- Even under this simplifying assumption, sampling may imply a loss of information:
  - Small details are lost.
  - Structures of the object may be misrepresented.

  We will detail on this in the next lecture.

Discretisation of Image Domain and Range (4)

Quantisation

- In most cases, also the range R_{phys} of the object function (i.e. the values of the physical property measured) is continuous.
- In digital images, the range R is discrete, since only a finite amount of information per sample is stored (e.g. one byte for representing a greyscale).
- *Quantisation* denotes the reduction of the continuous physical quantity to a discrete value.
- Typical choices for R:
  - scalars: e.g. the set $\{0, 1, \dots, 255\}$ in bytewise coded greyvalue images
  - vectors: e.g. in colour images where each of the three colour channels red, green and blue attains values within $\{0, 1, \dots, 255\}$.
  - matrices: e.g. in diffusion tensor images
- Besides the pure reduction to a discrete set of values, the mapping $R_{\text{phys}} \to R$ from physical values to image values can be nonlinear (often logarithmic or sigmoid). Linearity is a frequent but often simplifying assumption.

Discretisation of Image Domain and Range (5)

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- Quantisation introduces the *quantisation error*.
- Besides this, any measurement involves a *measurement error*.

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Overview of Forthcoming Topics

Concept

- Next lecture: Continue with basic concepts.
  - discussion of the sampling process
  - remarks on sensor fusion
- Starting from Lecture 3, we discuss particular image acquisition methods.
  - ordering criterion: medium of transmission
  - More than half of the lectures deal with imaging using electromagnetic waves (such as visible light, X-rays, and radio waves).
  - We discuss basic methods in more detail, derived ones in short.

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Planned Contents

1. **Basic Concepts**
2. **Introduction to the Electromagnetic Spectrum**
3. **Imaging with Visible Light and Nearby Ranges**
   - 3.1 2-D Visible Light Photography
   - 3.2 Optics and Camera Geometry, Light Perception, Sensorics
   - 3.3 Colour: Physics and Perception, Colour Spaces
   - 3.4 Infrared and Ultraviolet Light
   - 3.5 3-D Methods (e.g. stereography, holography)
4. **Imaging with Other Electromagnetic Waves**
   - 4.1 Micro-/Radio Waves (e.g. radioastronomy, radar)
   - 4.2 X-Ray and Gamma Ray Imaging
   - 4.3 3-D Imaging by X-Ray Tomography (e.g. CT)
5. **Magnetic Resonance Imaging**
   - 5.1 Classical MR Imaging
   - 5.2 Functional MR Imaging
   - 5.3 Diffusion Imaging (e.g. diffusion tensor MRI)

6. **Electron Microscopy**

7. **Acoustic Imaging**

   7.1 Sonar
   7.2 Ultrasound Imaging

8. **Summary**