

Lecture 31: Summary, Conclusions, Outlook

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What Have We Done? (1)

What Have We Done?

1. **Basics**
 - 1.1 Image Types and Discretisation (L1)
 - 1.2 Degradations in Digital Images (L2)
2. **Image Transformations**
 - 2.1 Fourier Transform (L3, L4)
 - 2.2 Image Pyramids (L5)
 - 2.3 Wavelet Transform (L6)
3. **Colour Perception and Colour Spaces** (L7)
4. **Image Compression** (L8)
5. **Image Interpolation** (L9)
6. **Image Enhancement**
 - 6.1 Point Operations (L10)
 - 6.2 Linear Filtering (L11)
 - 6.3 Wavelet Shrinkage, Median Filtering, M-Smothers (L12)
 - 6.4 Mathematical Morphology (L13)
 - 6.5 Diffusion Filtering (L14)
 - 6.6 Discrete / Continuous Variational Methods (L15, L16)
 - 6.7 Deblurring (L17)

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What Have We Done? (2)



7. Feature Extraction		1
7.1 Edges	(L18, L19)	2
7.2 Corners	(L19)	3
7.3 Lines and Circles	(L20)	4
8. Texture Analysis	(L21)	5
9. Segmentation		6
9.1 Classical Methods	(L22)	7
9.2 Optimisation Methods	(L23)	8
10. Image Sequence Analysis		9
10.1 Local Methods	(L24)	10
10.2 Variational Methods	(L25)	11
11. 3-D Reconstruction		12
11.1 Camera Geometry	(L26)	13
11.2 Stereo	(L27)	14
11.3 Shape-from-Shading	(L28)	15
12. Object Recognition		
12.1 Moment Invariances	(L29)	
12.2 Eigenspace Methods	(L30)	

What Were the General Principles?



What Were the General Principles?

From pixels to image understanding, from image processing to computer vision:

- ◆ Image transformations do not alter the image contents, but make them explicit in a more convenient way (e.g. in the Fourier domain).
- ◆ Image enhancement transforms a badly interpretable image into a more useful one (e.g. contrast enhancement, denoising, ...).
- ◆ Within image enhancement we went from local point operations via semilocal neighbourhood operations to global operations.
(e.g. greyscale rescaling → morphology → variational methods)
- ◆ Feature extraction is the first step for recognising semantically important structures (edges, corners, lines, circles).
- ◆ Segmentation decomposes an image into different objects.
- ◆ Optical flow describes motion in image sequences.
- ◆ The main goal of computer vision is to infer 3-D information from 2-D images (camera geometry, stereo reconstruction, shape-from-shading)
- ◆ The final goal is a robust object recognition from different views and under different transformations.

Which Mathematical Ideas were Important?

◆ *Formulating a problem as optimisation problem leads to transparent models:*● *local optimisation problems:*

least-square minimisation leads to the structure tensor:

- * edge detection in colour images (L19)
- * corner detections (L19)
- * optic flow methods of Lucas–Kanade or Bigün (L24)

● *global optimisation problems:*

variational methods that penalise deviations from model assumptions:

- * image enhancement (L15, L16)
- * deblurring (L17)
- * cartoon model of Mumford and Shah (L23)
- * optic flow method of Horn and Schunck (L25)
- * stereo reconstruction (L27)
- * shape-from-shading (L28)

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◆ *Choosing a suitable orthonormal basis eases many image analysis problems:*

- Fourier transforms (L3, L4):
filter design in the frequency domain
- discrete cosine transform (L8):
JPEG for image compression
- wavelet transform (L6, L8, L12):
compact coding, edge-preserving denoising
- eigenspace methods (L30):
compact representation of shape knowledge

◆ *Continuous models are often more transparent and allow to incorporate important invariances (e.g. rotation invariance):*

- continuous Fourier transform (L3)
- image interpolation (L9)
- diffusion filtering (L14)
- feature extraction: edges, corners, lines, circles (L18, L19, L20)
- variational methods (L16, L23, L25, L28, L29)
- geometry (L26, L27)
- object recognition with moment invariances (L29)

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Which Mathematical Ideas were Important? (3)



◆ *Almost the entire spectrum of mathematics is needed:*

- calculus:
derivative operators for feature extraction
- linear algebra:
basis changes, principal component analysis
- geometry:
pinhole camera model, epipolar geometry
- stochastics:
noise modelling, texture analysis
- numerical methods:
efficient solution of large systems of equations,
finite difference approximations, interpolation
- calculus of variations and differential equations:
Euler-Lagrange equations, diffusion equation

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What Interdisciplinary Ideas were Important? (1)



What Interdisciplinary Ideas were Important?

Ideas from Physics

- ◆ Diffusion filtering simulates diffusive mass and heat exchange.
- ◆ Dilation and erosion can be regarded as wavefront propagation (Huygens principle).

Ideas from Biology

- ◆ Colour perception (trichromatic vision) has motivated RGB colour processing.
- ◆ Important features and effects in machine vision are motivated from or also present in biological vision: edges, corners, filling-in effect.

Ideas from Geography and Related Sciences

- ◆ widespread in mathematical morphology
- ◆ Dilation can be interpreted as prairie fire propagation.
- ◆ Erosion simulates erosion in geology.
- ◆ Watersheds simulate watersheds in nature.

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Which Subjects were not Treated?

- ◆ *image acquisition methods:*
hardware-dependent and change more rapidly;
specialised classes available
- ◆ *image formats:*
scientifically not very interesting;
many conversion routines available
- ◆ *watermarking:*
has hardly entered textbooks yet
- ◆ *coupling with other sensor information:*
e.g. speech processing, distance sensors in robotics.
This area is still in its infancy.
- ◆ *stochastic methods:*
have been treated only if there are no deterministic alternatives:
noise models, texture analysis

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What are the Current Trends?

- ◆ *More Systematical Description of the Area*
 - Many seemingly unrelated methods serve the same purpose.
How are they related?
Are they even equivalent?
 - How far can one come using only a few basic principles (e.g. formulation as variational methods) ?
- ◆ *Extension of Scalar-Valued Methods to Vector- and Matrix-Valued Situations:*
 - partly triggered by inexpensive digital cameras, colour printers and new image acquisition techniques such as diffusion tensor MRI
 - Which methods can be generalised?
- ◆ *Highly Efficient Implementations:*
 - modern numerical algorithms
 - parallelisation
 - specific hardware such as GPUs

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What are the Current Trends? (1)



◆ *Knowledge Representation*

- How can one embed a-priori knowledge into image analysis methods?
- Lack of knowledge representation is one of the main reasons why computer vision systems often perform worse than humans.
- Machine learning can be very useful here.
- Stochastic methods are important in this area.

◆ *Merging of Computer Vision and Computer Graphics*

- Synthesis of real and virtual worlds requires e.g. the reconstruction of 3-D data from 2-D images of the real world and their embedding in a virtual 3-D scenario.

◆ *Closer Link to Robotics and Speech Processing*

- Exploiting all types of sensor information creates more robust systems.

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What Additional Classes are Offered?



What Additional Classes are Offered?

In the summer term 2008 our group is going to offer the following image analysis classes:

◆ **Differential Equations in Image Processing and Computer Vision**

- 4 + 2 hours, 9 credit points, by Joachim Weickert
- required for starting a master thesis in our group

◆ **Correspondence Problems in Computer Vision**

- 2 + 2 hours, 6 credit points, by Andrés Bruhn

◆ **Differential Geometric Aspects of Image Processing**

- 2 + 1 hours, 5 credit points, by Martin Welk

◆ **Numerical Algorithms for Visual Computing I**

- 2 + 2 hours, 6 credit points, by Michael Breuß

◆ **Seminar Processing of Matrix-Valued Images**

- by Stephan Didas

All classes are equally suitable for students of visual computing, mathematics, and computer science.

Bachelor's / master's theses on request. Just tell us your interests.

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New Study Programme: Master in Visual Computing

- ◆ pioneered by Saarland University
- ◆ deals with image acquisition, image analysis, image synthesis and related fields
- ◆ additional slot for filling individual gaps of knowledge (18 credits)
- ◆ very good job perspectives
- ◆ can be combined with other M.Sc. programmes such as computer science
- ◆ entrance requirements:
 - B.Sc. in computer science, mathematics, physics, electrical engineering, ...
 - good knowledge of English
- ◆ for more details, check out the web page

<http://www.master-visual-computing.de>

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Information on the Written Exam (1)

Information on the Written Exam

◆ When and Where Does It Take Place?

Friday, February 29, 2008 in the afternoon, from 2:00 to 5:00 p.m.

You are kindly asked to appear in the exam room not later than **1:45 p.m.**

The exam room depends on your family name:

- Adam – Kinzel: Lecture Hall I, E2.5 (Mathematics)
- Kroonder – Reuter: Lecture Hall II, E2.5 (Mathematics)
- Rickert – Zins: Lecture Hall III, E2.5 (Mathematics)

◆ Please Do Not Forget To Bring

- student identity card with photo (Studierendenausweis)
- course material from lectures and tutorial groups
- dictionary, if required (all questions are both in German and in English)

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◆ Please Do Not Bring:

- cellular phones
- books or copies of parts of books
- formulary (Formelsammlung), but handwritten notes are okay
- pocket calculator
- other aids

Everybody should have the same chances.

Much success and thanks for your interest in this class!

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