Semiar: Selected Topics in Variational Image Processing

Orientational meeting

WS 2014/2015

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Department of Computer Science
TU München

Objectives of the seminar

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- The last seminar is the week before Christmas.

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What you will learn in this seminar

Goals

- Get an impression of recent advances in variational image processing in various applications.
- Learn how to study a recent research paper and get a deep understanding of one particular topic.
- Write a scientific report.
- Practice giving scientific talks. Presentation skills!

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Requirements, or “is this something for me?”

Necessary

- Good background and interest in mathematics.
- Working knowledge about basic linear algebra and multivariable calculus in finite dimensions.

Recommended

- Computer Vision fundamentals from any basic course.
- Having heard about variational methods.

Important Dates

- First meeting: Today (02.07.2014)
- Fix assignment of papers and date.
- Weekly presentations starting on **Wednessday** Oct. 29th, **14:15-16:00**.
- Read and discuss your assigned topic with your supervisor **early**.
- Deliver and discuss your slides and the report **one week before your presentation**.

Preparation

Please do not work on your topic completely alone!

- Meet your supervisor at least **twice**.
- We recommend: Discuss your topic with your supervisor **one month before your talk**.
- We require: Deliver and discuss your slides and the report **one week before your presentation**.

Report

- The report should contain an **overview** and the **main contributions** of your assignment.
- Length: **5-7 pages**.
- Language: **English** or **German**.
- Write your report with **Latex** – a template will be available on the course web page.
- Send **PDF via email** to your supervisor

Presentation

- **35min talk** with **10min discussion** afterwards.
- Don't put too much information on one slide – 1-2 minutes per slide, i.e. not more than 35 slides!
- Language: **English**.
- You are free to choose the presentation software but need to export to PDF for discussion with your supervisor.
- Recommended structure:
  1. Introduction, problem motivation, outline
  2. Approach
  3. Experimental results (if there are any)
  4. Discussion
  5. Summary (of scientific contributions)

Evaluation Criteria

You will be evaluated based on the following criteria:

- Gained expertise in the topic.
- Quality of your talk.
- Quality of your report.
- Active participation in the seminar is expected (questions + comments after the talks).

- **Attendance of each seminar is mandatory**!
  In case of absence: medical certificate.

Lectures on related topics

Variational Methods for Computer Vision

- Structured introduction to variational methods.
- Learn variational modelling for several applications.

Recent advances in computer vision: Numerical Methods for Variational Image Analysis

- After the modeling one typically ends up with $\hat{u} = \arg\min_u E(u)$
- This lecture is about the theory and implementation of numerical optimization methods for actually solving the above problem.

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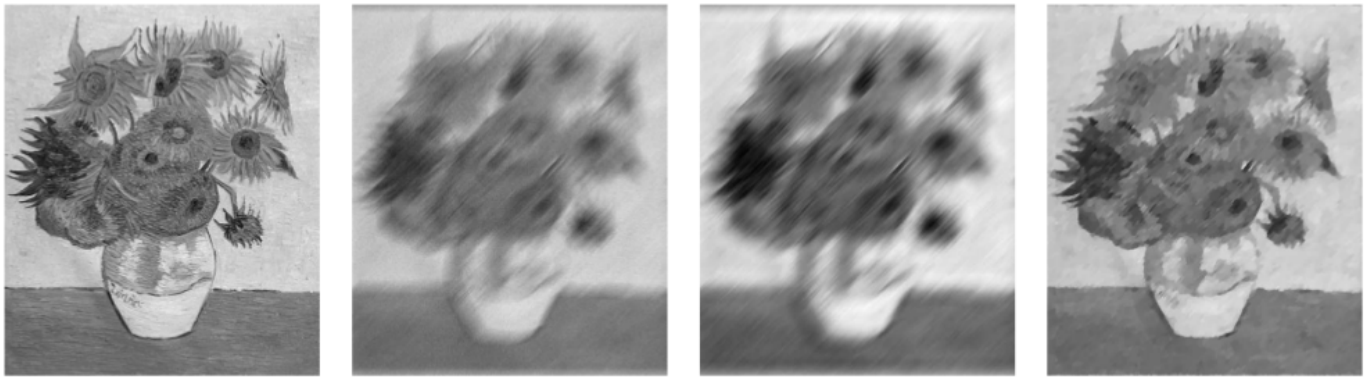
Overview of available topics

An Introduction to Total Variation for Image Analysis

- Regularization of ill-posed inverse problem $g = Au + n$.
- Total Variation is one of the most popular and versatile regularizers.
- Many interesting theoretical properties.



(a) Original image (b) Degraded image (c) Wiener filter (d) TV-deblurring

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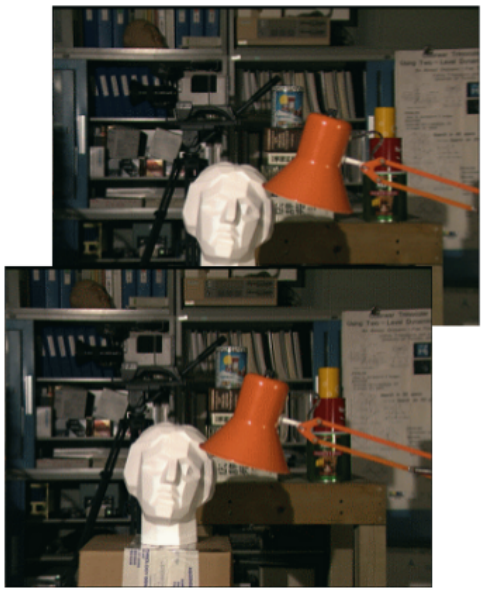
A Convex Formulation of Continuous Multi-Label Problems

- Convexify the following *nonconvex* energy:

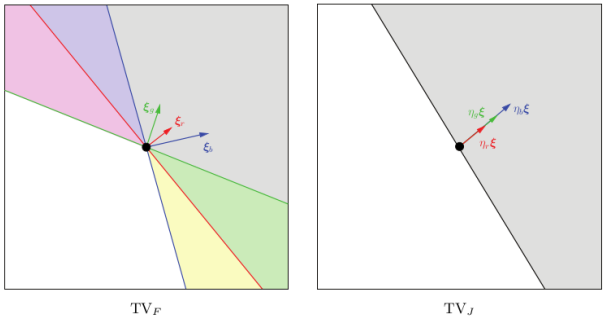
$$\min_{u:\Omega\to\mathbb{R}} \int_{\Omega} \rho(x, u(x)) + \|\nabla u(x)\| \, \mathrm{d}x$$

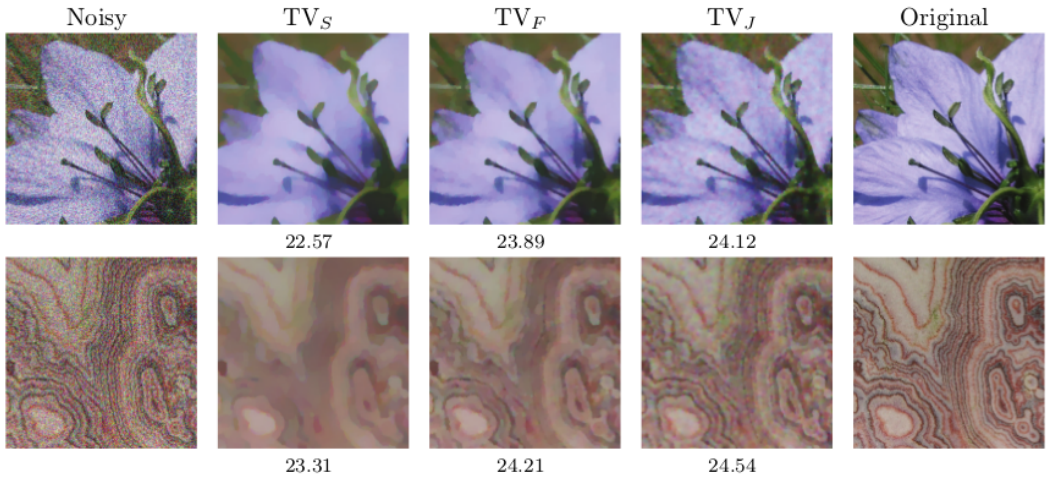
- Gives near globally optimal solutions independent of initialization. Application here: Stereo matching.



An Approach to Vectorial Total Variation based on Geometric Measure Theory

- Generalization of TV to vectorial data such as color images.
- Forces jumps in the color channels to have the same direction.
- Dual formulation allows for efficient optimization.





Spectral Total Variation Decomposition

$$\partial_t u(t) = -\, p(t) \;\; \text{s.t. } p(t) \in \partial \left\| \sqrt{(\partial_x u(t))^2 + (\partial_y u(t))^2} \right\|_1$$

Generalizing what the Fourier transform is for frequencies.

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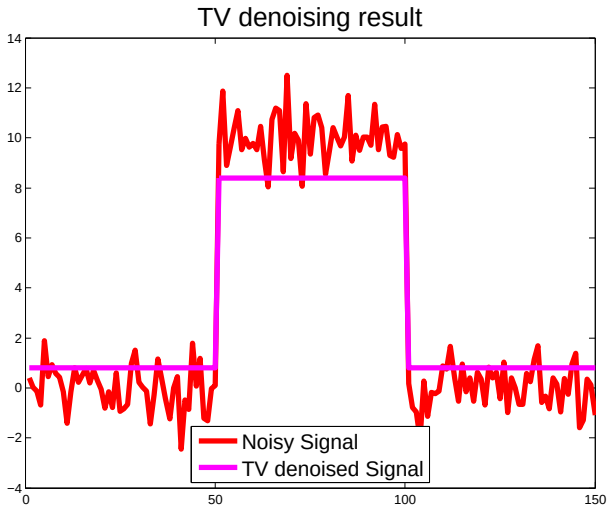
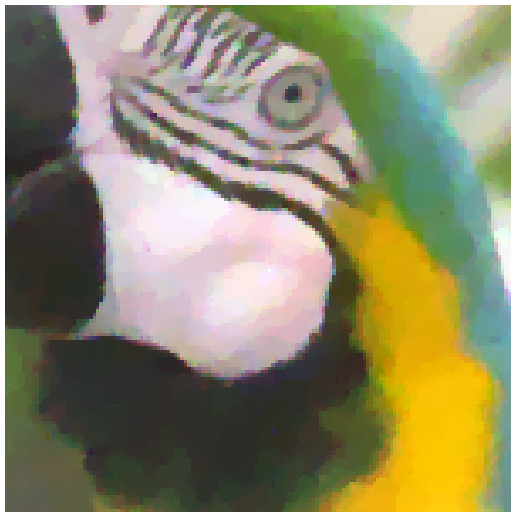
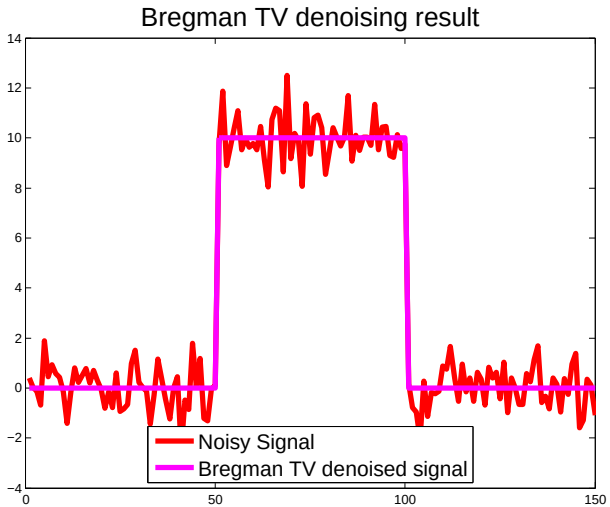
Bregman Iterations

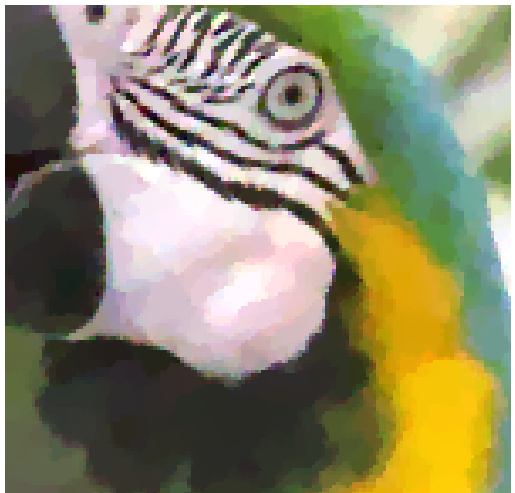
$$\min_u \|Au - f\|^2 + J(u) - \langle p^k, u \rangle \quad \text{s.t. } p^k \in \partial J(u^k)$$

Correcting the loss of contrast of variational approaches.









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Exemplar-Based Image Inpainting

- The challenge is to remove large objects from digital images and fill in the hole in a visually plausible way.
- Idea: Instead to propagating neighbouring pixel information use a non-local variational scheme and fill in using similar image patches.

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Linear Diffusion based Image Compression

- Find a sparse set of pixels which represents the image “well” enough so that the original image can be restored using linear diffusion.
- State-of-the-art image compression (outperforms JPEG).
- Difficult nonconvex optimization problem.

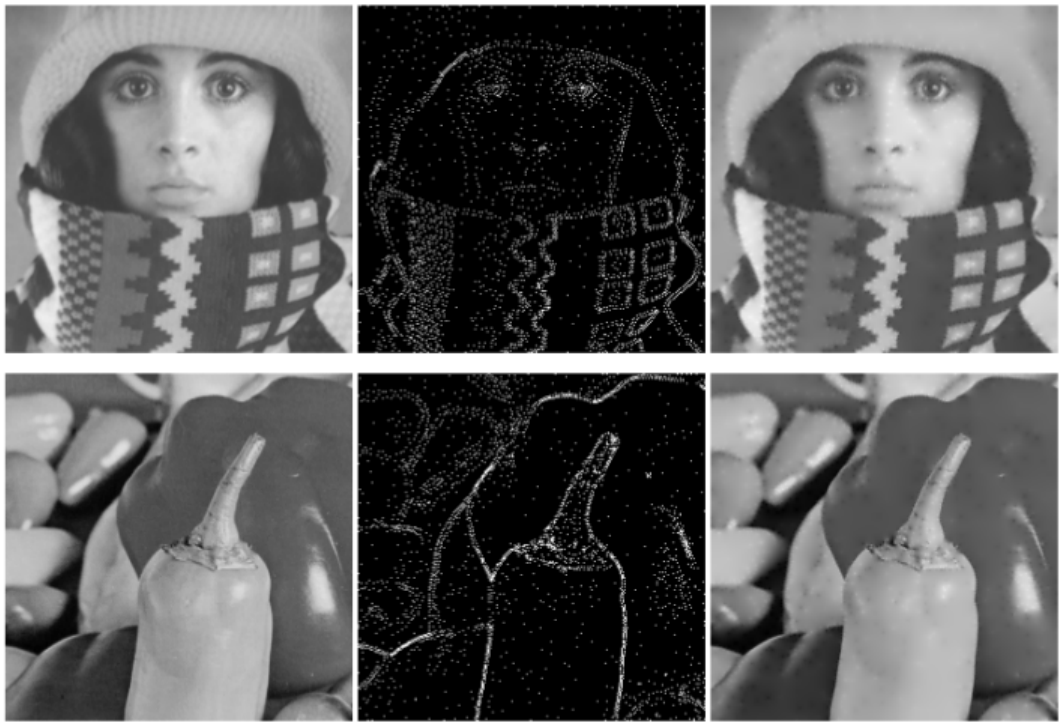

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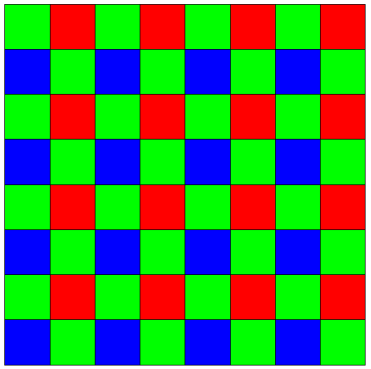
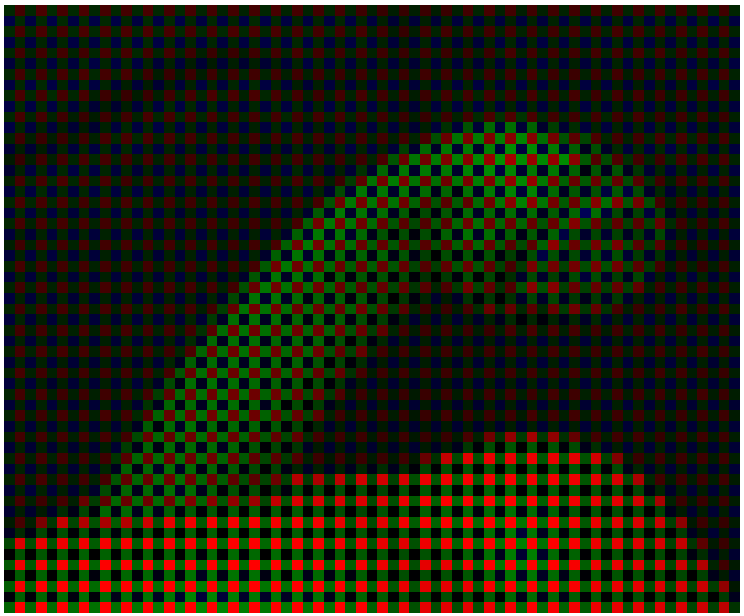
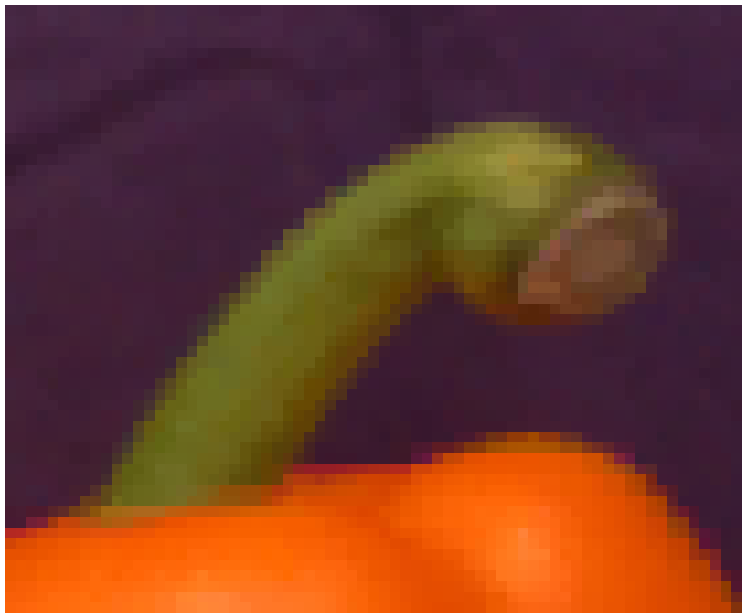
Image Demosaicking

- Cameras only record one color per pixel.
- Sensors have a certain pattern of colors.
- Interpolating missing colors: *Demosaicking*
- $\min_u \|P_I u - f\|^2 + \mu R(u)$







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Dithering by Differences of Convex Functions

- Visually approximate input image by 1-bit black and white image.
- Model: Electrostatic attraction (convex) plus repulsion (concave) functional.
- Numerical optimization: DC programming.

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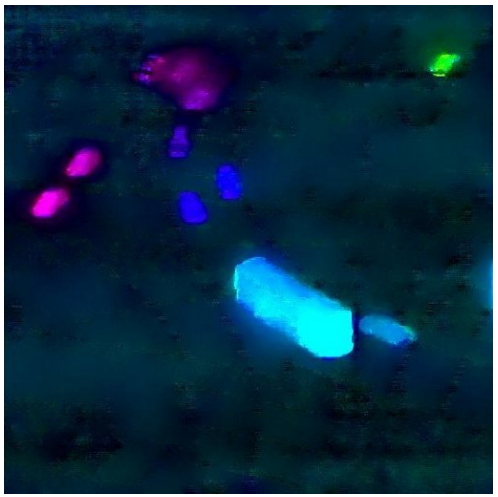
Variational Optical Flow

- Given two consecutive images, one looks for a motion field which maps corresponding pixels to one another.
- The overall problem can be formulated in a variational framework via an optimization problem:

$$\min_v \int_\Omega |I_0(x) - I_1(x + v(x))|^2 + J(v)$$





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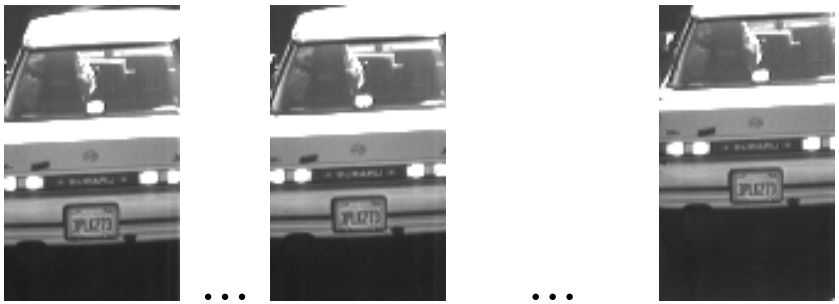
Variational Super Resolution

- Given a set of low resolution images, construct a high resolution image.
- Exploit redundancy of the input frames and solve an optimization problem of the form:

$$\min_u \sum_i \|DBW_i u - f_i\|_2^2 + J(u)$$

16 input images



Super-resolution $\xi = 3$

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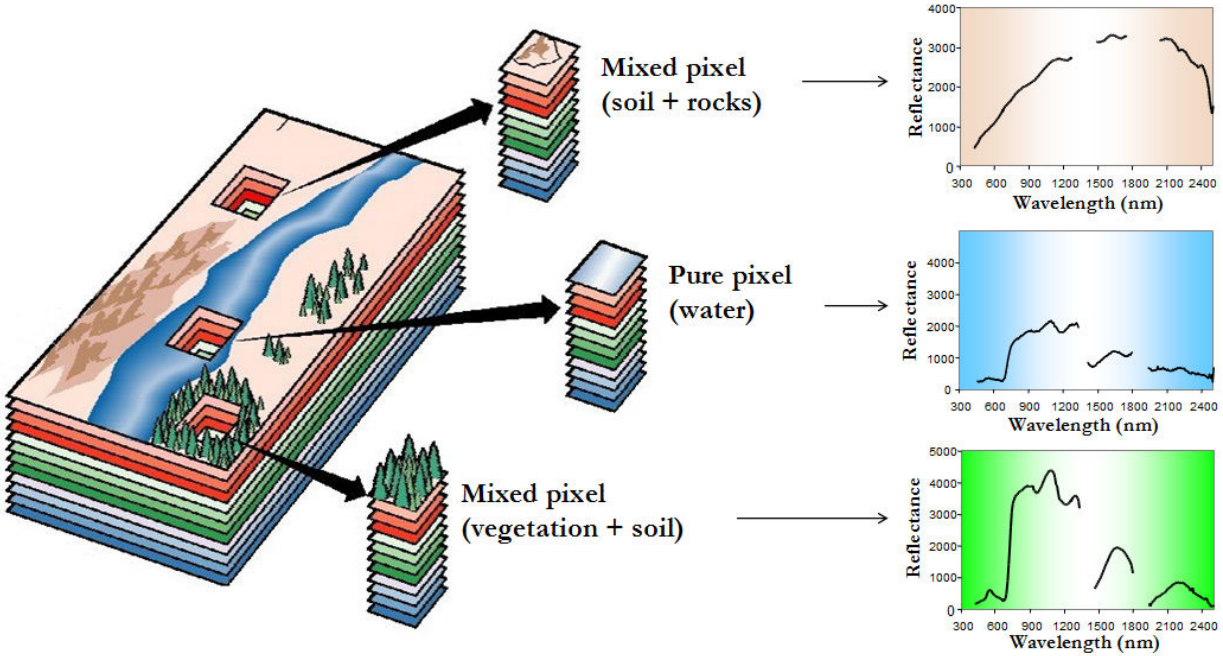
Hyperspectral Unmixing



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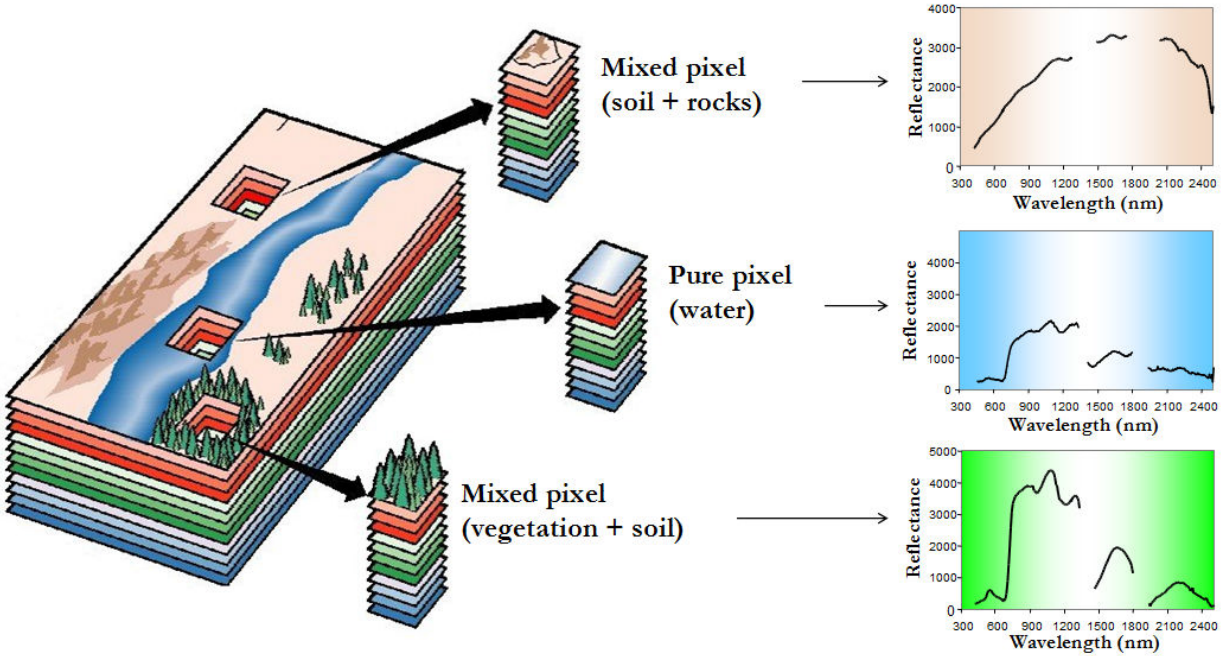
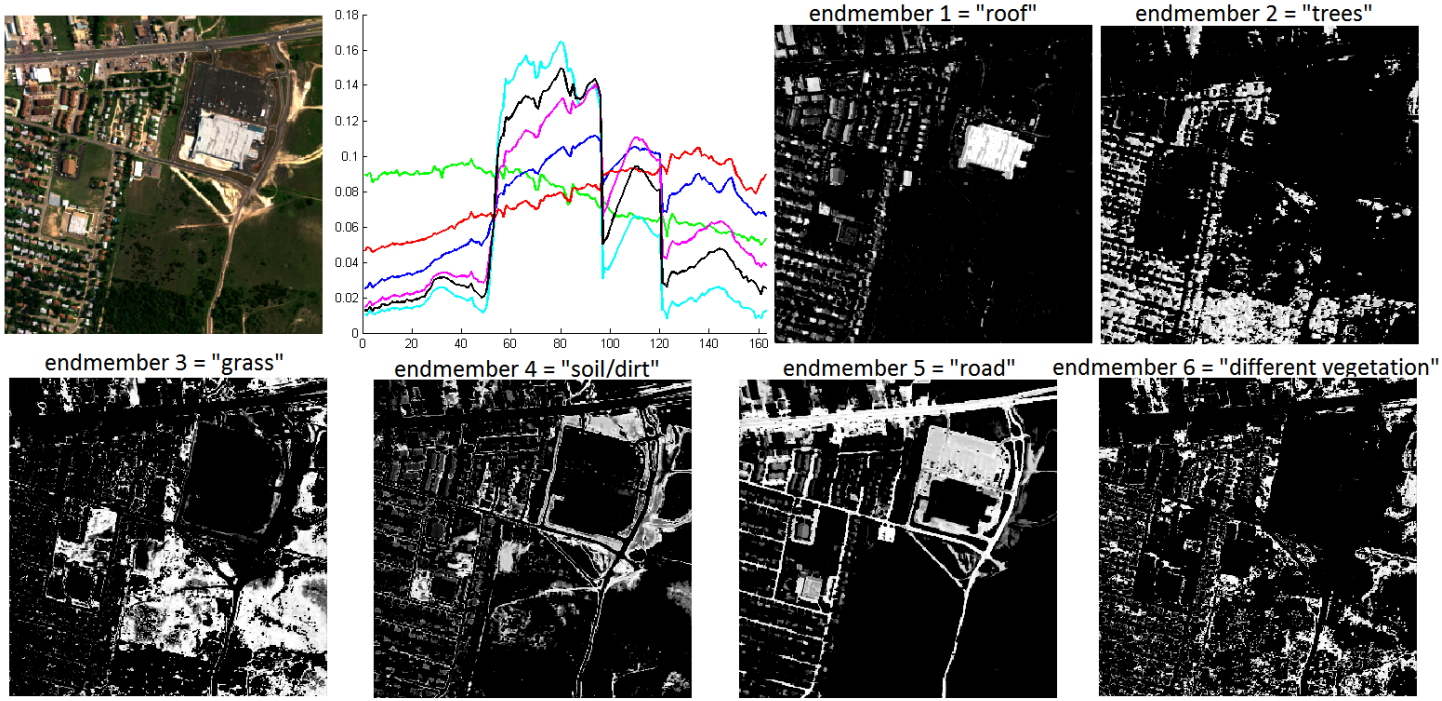




Pan-Sharpening

Image fusion with local and nonlocal priors:

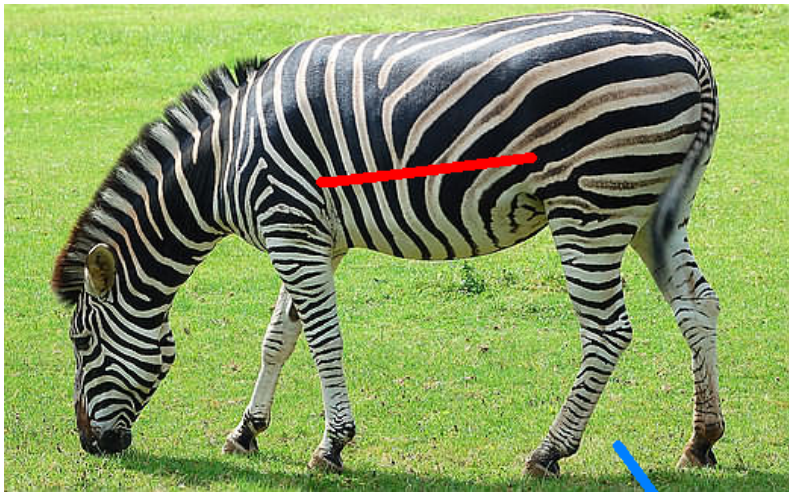
$$\min_u \frac{1}{2} \left\| \sum_i \alpha_i u_i - f \right\|^2 + \frac{\mu}{2} \sum_i \|(\downarrow k) * u_i - g_i\| + \nu R(u)$$

High res. gray scale f + low res. color g = high res. color u

Globally Optimal Two Phase Segmentation

- We wish to dissect an input image in two spatially consistent segments.
- Encode the segmentation as a binary valued function $u(x) \in \{0, 1\}$ and solve a relaxed version of the following optimization problem:

$$\min_u J(u) + \int_\Omega u(x)\rho(x) \; dx$$



Singular Vectors of Variational Regularizations

Well known: singular value decomposition of matrices.

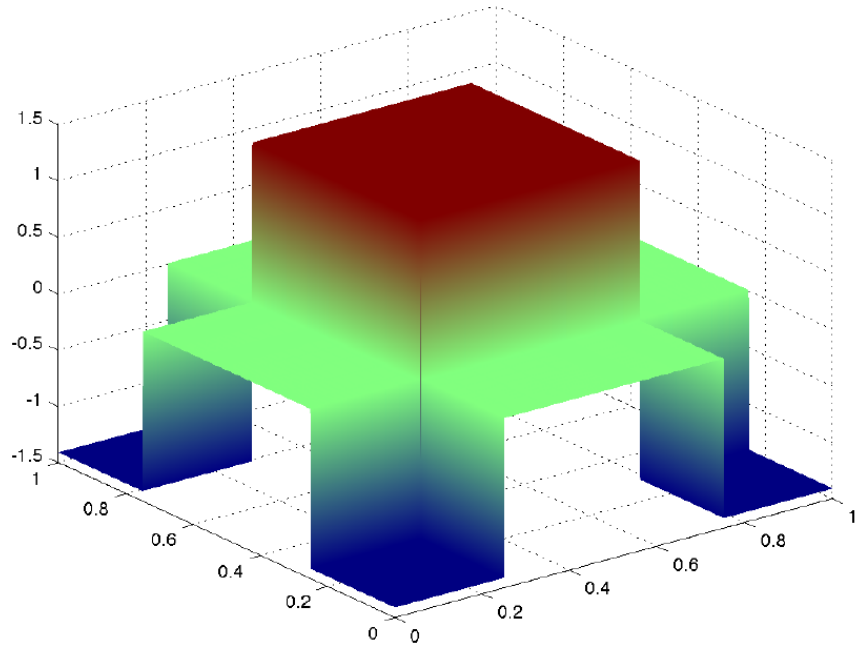
$$K^T K u = \alpha u$$

define $\lambda = 1/\alpha$, $J(u) = \frac{1}{2}\|u\|^2$. Generalization

$$\lambda K^T K u \in \partial J(u)$$

What happens for other J, e.g. $J(u) = TV(u)$?

- Is there an orthonormal basis of singular vectors?
- What properties do singular vectors have?



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Multilabel Segmentation

- We wish to find multiple consistent regions of an input image based on user input, color or texture.
- Formulate this combinatorial problem as a variational problem in the following way:

$$\min_u \sum_i^n \int_\Omega u_i(x)\rho_i(x) \; dx + J(u)$$

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Register and select your favorite topics

If you would like to participate in the seminar,

1. **First** register for the seminar at campus.tum.de
   Registration is open Thursday 03.07.2014 at 10:00 with space for 15 participants.
2. **After you are registered** send an email with your **name** and your **three favorite topics** (ranked 1,2,3) to **moellerm@in.tum.de**.

Only people that registered at campus.tum.de can participate in the seminar.

End

Any questions?

These slides will be available online at
https://vision.in.tum.de/teaching/ws2014/vms2014
Password: imageprocessing