A generic task in modern image processing is image registration, needed for integration and/or comparison of data obtained from different images. Particularly in a medical environment, there is a huge demand for comparing pre- and post-intervention images, integrating modalities like anatomy (obtained, e.g., from computer tomography) and functionality (obtained, e.g., from positron emission tomography), motion correction and/or reconstruction of two-dimensional projections from a three-dimensional volume (applies to all tomography techniques and histology). The problem is easily stated: given two images (a reference and a template image), find a transformation, such that the transformed image is similar to the reference image.

In this lecture we present a general and unified approach to image registration. The course covers central problems arising in typical applications. In particular, we address the following topics.

- **applications** we present a variety of applications and comment on similarities and particularities
- **general problem** the central question is identified and translated to a general and formal description
- **images** this basic introduction to images covers image interpretation, interpolation, approximation, and deformations
- **medical images** we comment on some of the particularities of medical images such as, e.g., X-ray, CT, MRI, SPECT, ultrasound
- **feature based registration** an efficient and straightforward approach to registration is based on image features; particular features are located and related, the computed transformation is based on the correspondence of these features
- **similarity or distance** similarity of image is of course one of the central questions; we comment on different approaches (sum of squared differences, correlation, mutual information, gradient fields, . . . ) and discuss pros and cons
parametric registration many registration techniques are based on a parameterized transformation; we introduce a universal approach and present particular specifications (e.g., rigid, affine, splines)

non-parametric registration the most advanced techniques are so-called non-parametric registrations, like, e.g., elastic or fluid registration; in contrast to parametric registration, the transformation is not restricted to a finite dimensional space; we comment on ill-posedness and regularization; following the calculus of variations, we give a strict approach to non-parametric registration

numerical methods all parts of the lectures are combined with practical aspects, including implementation (see also “exercises”); we introduce image processing tools, optimization schemes and – for non-parametric registration – also basics for partial differential equations and its discretization

constrained registration we also answer the question on how to add additional application dependent information on the registration problem; particularly, we discuss a combination of landmarks and volumetric distance measures, the segregation of spaces, volume preserving, and volume constrained transformations

exercises our exercises present a fundament ingredient of this course, the exercises complete the understanding of the underlying theory and concepts; in particular, we enable the participants to write their own programs for proper image transformation, rigid and affine registration, and elastic registration

our exercises are based on MATLAB, see http://www.mathworks.com/; knowledge of MATLAB is nice to have but not presumed

conclusions we close the course with concluding remarks on topics not addressed within the course, supplementing remarks, and comments on recent developments in registration