Computer analysis of dynamic studies in medical imaging

Václav Krajíček
Vaclav.Krajicek@mff.cuni.cz

Department of Software and Computer Science Education
Faculty of Mathematics and Physics
Charles University
Outline

- Overview
- Examples
- Registration
- Segmentation
- Classification
- Conclusion
Medical imaging

- Diagnosis, CAD, CAS, surgery planning
  - Non-invasive, expensive
- Alternatives are often worse
  - Exploratory surgery, histological examination, biopsy
- Computer science
  - Visualization
  - Image processing
- Other fields
  - Physics
  - Engineering
  - Medicine
Image data

- **Dimensions**
  - 2D, 3D, 4D

- **Modalities**
  - Physical properties, contrast agents

- **Machines**
  - RTG, ultrasound, CT, MRI, PET, SPECT
Medical images analysis I

- Processing large amount of data
  - Screening programs, repeated examinations
  - Routine vs. specialized
  - Lack of radiologist experts
- Manual examination
  - Time consuming, Most cases
- Semiautomatic
  - Visualization, GUI tools
- CAD
  - Work flow + tools
  - Specialized tasks (mammography, colonoscopy)
Medical images analysis II

- Automatic tools
  - Simple tasks
- CAS
- Surgery planning
- Training
- Medical research
  - Measurement, statistical studies
  - Special tools/methods
Medical images analysis III

- Computational power to help with tedious tasks
  - Simple tasks but on large datasets
  - Complex and subjective tasks

- Image processing
  - Preprocessing, Segmentation, Registration, ...

Acquisition  Preprocessing  Registration  Segmentation

Validation  Decision  Visualization  Classification
Outline

- Overview
- Examples
- Registration
- Segmentation
- Classification
- Conclusion
Example 1

- From single image

Acquisition

Preprocessing

Classification

Visualization
Example 2

- Diagnosis based on several images
- Kidney development (pre, post)
- Interested in growth, shrinking
Example 3

- Mammograms comparison [Timp 07]
- Registration
- 2D image, high resolution
- Assessment, track down decision failures
Example 3
Example 4

- Our case study [Krajicek 08]
- DCE-MRI of breast
- Registration of images sequence
- Enhancement curve, classification
Example 4
DCE-MRI

- Shape of an enhancement curve
  - Contrast agent
Outline

- Overview
- Examples
- **Registration**
- Segmentation
- Classification
- Conclusion
Registration

- Task definition
  - Mathematical optimization
    \[ \min_T(S(A, T(B))) \]
  - Categorization
    - Rigid, Non-rigid, pixel-based, feature-based
  - Choice of S & T
- Elastic deformations
  - Mathematically approximated
- Different images
  - Goes against similarity optimization
Registration

- DCE-MRI registration research

  - [Ruckert 98] [Ruckert 99a] [Ruckert 99b], FFD based transformation
Registration

- DCE-MRI registration research
  - [Ruckert 98] [Hayton 99], Mutual Information similarity measure
    \[ MI(A, T(B)) = H(A) + H(T(B)) - H(A, T(B)) \]
    \[ H(A) = -\sum_{x \in A} p(x) \log p(x) \]
    \[ H(A, B) = -\sum_{x \in A, y \in B} p(x, y) \log p(x, y) \]
  - Joint histogram
Registration

- DCE-MRI registration research
  - [Hayton 97], Pharmacokinetic Model
    - Models changes in intensity between adjacent images
    - Expected error

\[ M(t) = \frac{A}{a-b} (\exp^{-bt} - \exp^{-at}) \]
Physical models

- [Rohlfing 03], Incompressibility constraint
- [Tanner 05], Physical simulation of deformations
  - Method of assessment
  - Strategy of best registration technique choice
    - Virtual phantom + deformations
- Finite elements
  - Engineering
  - Modeling of stress & strain
  - ANSYS
Physical models
Outline

- Overview
- Examples
- Registration
- Segmentation
- Classification
- Conclusion
Segmentation

- Task definition

\[ \{ I_n, I_n \subset I, n=1..N \}, I = \bigcup I_n, N \ll |I| \]

- Methods tailored for DCE-MRI
  - Based on enhancement curve
  - Thresholding
  - Clustering
  - Region growing

- Results in several “blobs” and background

- Less research on segmentation of temporal data
Lesions segmentation, [Tanner 04]
- ROI
- back/foreground

Criterion

\[
\arg\max_k P(C_k|x) = P(x|C_k)P(C_k)
\]

\[
\frac{P(x|C_1)}{P(x|C_2)} > \theta
\]

\[
P(x|C_k) \quad \text{Est. from initial}
\]

\[
P(C_k)
\]
Outline

- Overview
- Examples
- Registration
- Segmentation
- Classification
- Conclusion
Classification

- Task definition

\[ \{(x_n, c_n), x_n \in M, c_n \in N\}, |N| \ll |M| \]

- Various properties of blobs, **features**

- Classification algorithm - learning
  - Way of finding rule to classify unknown sample using group of known samples – training set
  - Rule – e.g. value of discriminant function, nearest cluster center
  - Optimization task
    - Objective function
Features

- Vectors of numbers
- Various properties of blobs, **features**
  - Shape – compactness, topology value, irregularity, …
  - Margin – maximum gradient, variance of max. gradient
  - Kinetic – enhancement curve, slope, time to max, …
  - Texture – Haralick features, co-occurrence matrix
  - Other – age
- Too much
  - Does not improve separability of features space
Features selection

- Reduce number of features
- Manually remove
- Unsupervised selection
  - features correlation
  - cluster similarity
  - bottom-up, top-down
  - suboptimal
Assessment

- Specificity, sensitivity, accuracy

<table>
<thead>
<tr>
<th>detected \ actual</th>
<th>malign</th>
<th>benign</th>
</tr>
</thead>
<tbody>
<tr>
<td>malign</td>
<td>TP</td>
<td>FP</td>
</tr>
<tr>
<td>benign</td>
<td>FN</td>
<td>TN</td>
</tr>
</tbody>
</table>

- ROC curve
  - FP & TP trade off
  - Area Under ROC (AUC)
  - Variability of decision criterion

- Cross-validation
  - Due to limited amount of data
Outline

- Overview
- Examples
- Registration
- Segmentation
- Classification

Conclusion
Conclusion

- Medical image processing
  - Serious, difficult discipline
  - Slowly getting into practice

- Processing of sequences is complex task
  - Trade off between spatial and temporal resolution
  - Employs many image processing subtasks
  - Large datasets - 4D

- Brest DCE-MRI
  - Wide research on registration
  - Less on segmentation
  - Specific approach to classification (features)
References

[Hayton 97]

[Hayton 99] A non-rigid registration algorithm for dynamic breast MR images

[Ruckert 98] Non-rigid Registration of Breast MR Images Using Mutual Information

[Ruckert 99a] Non-rigid registration using free-form deformations: Application to breast MR images

[Ruckert 99b]

[Tanner 04] Classification Improvement by Segmentation Refinement: Application to Contrast-Enhanced MR-Mammography

[Tanner 05] Registration and Lesion Classification of Contrast-Enhanced Magnetic Resonance Breast Images

[Timp 07] Temporal Change Analysis for Characterization of Mass Lesions in Mammography

[Krajicek 08] Analyzing contrast enhanced MRI sequences for mammography