Thesis Outline

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1 Introduction

Opening Notes

- Medical imaging, particularly in the context of registration
- Analysis of images in the studies of a group: structural change, inter- and intra-subject, etc.
- The *need* to compare images

Non-Rigid Registration (NRR)

- The Purpose of Registration
- Alignment of images
- Subsequent analysis of change
- Performing comparisons; task simplified owing to NRR

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Models

- Identification of corresponding points across image sets
- Alignment of corresponding point using non-rigid registration
- Comparison independent of pose variations (thus a like-with-like comparison)
- Models embody 'knowledge' about structures of interest
- Explanation of the variation using decomposition, which is inherent in the models

The Tie Between NRR and Models

- Registration infers a particular dense (pixel-to-pixel/voxel-to-voxel) correspondence
- Models require correspondence to be built
- Good models benefit from good NRR
- Registration can be build models by producing correspondences

Optimal Shapes and Assessment of Shape Models

- An idea that was put to practice before (successfully so)
- Find corresponding points that define contours (outline of constituent structures in ROI). This is not yet automated.
- Identify points of interest, e.g. edges
- Describe shape by applying principal component analysis to points distribution
- Define descriptor of shape model's 'quality', based on key attributes
- Identify optimal models, use an objective function to accommodate and use figures of merit

Aims Of the Project

- Extend work on shape, generalise it to account for and incorporate intensity information
- Obviate the need to segment structures, make the model-build framework automatic
- Combine NRR and models to form a joint framework

- This involves assessment of appearance model (shape and intensity), as well as use of an objective function builds good models
- Assess NRR

Extending the Existing Framework (Shape ▷ Appearance)

Assessment of Registration

Cover work that is contained in the heart of the thesis (a gist)

- Benchmark existing registration methods (problem perceived 'in reverse')
- Build models automatically
- Data-driven analysis
  - ▷ Models without human intervention
  - ▷ Registration assessment without annotation

Contributions

- Rapid evaluation of registrations, without need for ground truth
- Reason about quality of different NRR algorithms
- Build models automatically
- Evaluate models
- Complete framework for automatic or semi-automatic analysis of data

Thesis Organisation

2 Non-rigid Registration

- Registration involves warping and similarity measures

2.1 Image Warping

- Rigid, affine, and non-rigid transformations
- Methods (splines, diffeomorphic warps and functions, deformation fields, etc.)

2.2 Similarity Measures

Introduction

- Purpose
- General technical details

Methods

- MSD/SSD
- Correlation ratio
- Mutual information
- Model-based (to be described later, among newly-developed methods)

2.3 Group-wise versus Pair-wise

(*Possibly omitted, depending if space permits*)

- Introduction: the distinction between the two
- Discussion: Flaws associated with pair-wise NRR
- Examples/results
- Previous work on group-wise registration

2.4 Existing NRR Assessment Methods

- Presenting the main methods in current use
- Elaborate on generalised overlap-based assessment - Tanimoto and Dice (the latter in brevity)

3 Models

3.1 Statistical Models

Introduction

- Method for describing variation in data

Rationale

- Image analysis
- Synthesis (which includes extrapolation from the given data), fitting to data
- Thesis introduces an important new application of models

3.2 Shape Models

Deformable Models

- The principles
- Bending energy
- Practical example/s

Correspondence

- The need for corresponding points
- Vectorisation and embedment in space

Principal Component Analysis

- The principles of the method
- Mathematics involved
- Issues and weaknesses (e.g. banana-shaped distributions and linearity of the models, which are later introduced in a technical context)

Model Construction

- More elaborate discussion, in relation to PCA
- Equations to follow

Shape Models

- Learning how shapes vary in a set
- Construction process, including equations, alignment to CoG
- Visualisation of the models in practical use

3.3 Appearance Models

Intensity Models

- Introduction of the second type of variation, which is 'texture'.
- Construction using normalisation, warping to mean, raster scan, etc.
- Visualisation of the concept

Combined Models

- Formulation that involves and brings together the above, examples included

3.4 Active Models and Fitting

- Matching using the notion of *synthesis*
- Discrepancy as a deficiency, which later comes into play
- Computing distance from a match/fit to an unseen image (relating to shuffle distance, to be discussed later)

4 MDL Shape Models

4.1 Shapes and Correspondence

- Returning to the issue of point correspondence
- Exemplifying models where correspondences are poor

4.2 Learning Shapes

- Principled approach

4.3 Objective Function and Optimisation

- Variety of functions
- Optimising correspondences
- Objective function
- Determinant-based optimisation
- Minimum description length
- Numerical results from past work
- More results and illustrations (visual)

5 Model-Based Registration

5.1 Model-based Registration

- Initial Experiments to demonstrate feasibility
- Data - description, images
- Clamped-plate spline-based warps
- Determinant-based objective function
- MDL objective function

- Experiments
- Results

5.2 Model Building

- Introduction and validation (before next chapter on evaluation begin)
- Models built from 1-D model-based registration
- Personal contribution to full implementation in 2- and 3-D
- Examples of 2-D models

6 Assessment of Models and Non-Rigid Registration

Generalisation and Specificity

- Applied to images (extension of work on shapes)
- Synthesis, clouds in hyperspace
- Need image distances to be measured

Image distance measures

- Euclidean distance
- Use of the shuffle distance
- Nearest match to identical pixel intensity (Wang)
- Efficient implementation and *ad hoc* optimisations

Normalisation

- Entropy

7 Validation Methodology and Experiments

- Controlled perturbation
- Definition of sensitivity
- Comparison with overlap

8 Application to Non-Rigid Registration Evaluation

- Groupwise vs. pairwise discussion
- Experiments involving different NRR algorithms and quantitative comparison

9 Extensions to 3-D

3-D Extension of the Method

10 Future Exploration

10.1 Pitfalls

- Long time to synthesise many images and compute distances
- Computation of Sensitivity and Generalisation not principled, corrected by pseudo-entropy of graphs

10.2 Extending the Scheme

- Normalisation
- Improving the range of displacements where results can be differentiated
- Improving sensitivity further

11 Conclusions

Summary, discussion, contributions and conclusions

- Building models without human intervention
- Developed a model-based objective function
- Model evaluation scheme
- Registration evaluation scheme
- Group-wise registration better than pair-wise

12 Appendices

- Perturbation
- Formulation of error bar calculations
- Objective function for model-based registration
- ...