The Analysis of temporal series, Data reduction and Image Fusion

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Image processing in general

- Aims of image processing
  - Detection
  - Measurement
  - Description

- Pre-Processing
- Manipulation
- Assessment

- Types of data
  - 3D in time with multiple channels

Histogram Equalization
Some Image Processing Tools

- Transforms | filters
  - choose basis function
  - transform
  - filter “eigenvalues”
  - inverse operation

- Solution to inverse problems
  - set up forward model
  - solve

- Hierarchical descriptions
  - combine
  - classify
  - isolate

- Model fitting
  - find model
  - find distance measure
  - minimise
Problem:
• Place of ‘running’ birds (ratites) with respect to other birds

Method:
• Supertree of relationships

Collaboration avec S Edwards (Seattle, USA) et H Philippe (Paris, France)
Why is image recognition so difficult for a computer?
<table>
<thead>
<tr>
<th>High level</th>
<th>Goal</th>
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<td>State of structure</td>
<td>forward/backwards chaining</td>
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<td>Clinical condition</td>
<td>Objects</td>
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<td>Intermediate</td>
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<td>Structures</td>
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<td>Organs</td>
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<td>Low level</td>
<td>local/global</td>
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<td>Lines, edges, tubes</td>
<td>Agents</td>
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<td>Pixel</td>
<td>serial/parallel</td>
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<td>standard image processing</td>
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</table>
Using A-priori knowledge

- Statistical pattern recognition
- Syntactic pattern recognition
- Model based constraints
- Knowledge based methods

- Going towards the right solution
- Avoiding bias
- Including the observer
- Solving higher level problems

Knowledge based engine

- Specific medical
- General medical
- General

- Case
- Image
- Problem solving
PostModernism

Any representation of the real world is bound to be self-referential using any combination of language, mathematics and symbols [Variation on Heisenberg uncertainty]

“Everything I say is false”
Data driven v. Hypothesis driven methods

- **Hypothesis driven**
  - find a (null) hypothesis
  - generate statistical test

- **Data driven**
  - look at data
  - suggest hypothesis

- **Constraints**
  - limit search space
  - investigate hypotheses
    based on a priori knowledge
Boundary conditions/Constraints

- **Physical**
  - spatial extent
  - positivity
  - initial/final states
  - statistical variation
  - regional
  - deterministic

- **Context**
  - classification
  - model based
    - Statistical
  - measurable (volume, biochemical level, etc)
  - comparable (before/after, this/that)
Handling of temporal data

Special class of 3-D data processing
- Looking for change
- Looking for (derived) function

Consider set of time curves for every pixel
- Dual curve/image data set

Weather Satellites
Cardiac registration
Data compression/projection

- Removing redundancy
- Reducing dimensionality
- Projection against
  - time (summation)
  - y (vertical axis)
  - oblique
- Constraints are required (a priori information)
For cyclical function

\[ A[i,j] = \sum_k C[i,j,k] \cos(\omega k) \]
\[ B[i,j] = \sum_k C[i,j,k] \sin(\omega k) \]

\[ \text{AMP}[i,j] = \sqrt{A[i,j]^2 + B[i,j]^2} \]
\[ \text{PHASE}[i,j] = \tan^{-1}\left(\frac{B[i,j]}{A[i,j]}\right) \]

First Fourier component
Functional Images

- Image of a derived function
  - Rate of increase/decrease
  - Time to max
  - Variance image

- Example Kalman filtering
  - Estimating current values
  - And statistical model
Shape Descriptors

- Skeletonization
  - Circumferences
    - chain code
    - Fourier etc
  - Snakes
  - Active shape models
- Cores
  - (3-D) multiscale medial axes
- Composite
Fourier Contours
Active Shape Model
A simple example

- A set of triangles

- Characterised by 6 parameters
  - \{x_1,y_1,x_2,y_2,x_3,y_3\}

- Simpler description possible
Triangle space

- Fix the origin
- Fix the x axis
- 3 parameters
- Also lengths of 3 sides

$X_1,Y_1$
Normalise scale

- Take ratios of lengths of 1 side v. other two
- Two dimensional space
Where to place the nodes

- Regular
- Maximum radius of curvature
- Minimal description length
3D deformations

(a) and (b) show different views of the brain, while (c) demonstrates surface matching with labeled brain regions.

Acknowledgment: Thompson

Surface Matching

- CENT
- SFS
- SYLV
- STS

(c) and (d) illustrate the application of the method to different brain structures.
Model based approach

- \( Y = X + \varepsilon \)
  - \( Y \) is data matrix \((m,n)\)
  - \( X \) is model
  - \( \varepsilon \) is error

- Decompose
  - \( X = FG' \)
    - \( F \) \((m,k)\)
    - \( G \) \((k,n)\)
- F are Principal Axes
- G are Weights (variance)

- C (covariance matrix)
  - $C = (Y - y_m)' (Y - y_m)$
Oblique rotation

- PCA solution is orthogonal
- Make linear combinations
  - Oblique rotation
  - To satisfy constraint (positivity)
  - For example is higher dimensional space
Factor analysis: an example

- Decomposition into principal component
- Oblique rotation (based on constraints)
- Display of images (eigenfunctions) and curves (eigenvalues)
- Segmentation, model fitting and quantitation
Independent Component Analysis

- Cocktail party problem
- Assume signals strictly independent
- Prewhitening

- Components not ordered.
Whitened signals and density
Separated signals after 2 steps of FastICA
Separated signals after 3 steps of FastICA
Separated signals after 4 steps of FastICA
Separated signals after 5 steps of FastICA
Spectral Analysis

Series of spectral images

\[ x_i(e) = \sum_{k} a_k(i)f_k(e) + \varepsilon_i(e) \]

pixel \( i \)

= \[ p_{Tc}(i) \]

= \[ p_i(i) \]

+ \[ s_1(i) \]

+ \[ s_2(i) \]

+ \[ s_3(i) \]
Confocal microscopy


Temporal sequence
(double marking thiazole orange - Fast Red)

4D sequence
(double marking Hoechst - Europium)
Labelled leucemic cells
Image Registration and Fusion

- **Registration**
  To find relationship between two (or more) data sets so as to be able to co-register all parts of the data

- **Fusion**
  To compare data from different sources, or at different times/procedures so as to extract common information (including display)
Fusion display and extraction of common information

- Checkerboard display
- 3-D display with colour overlay on surface
- Common markers and see through
- Joint measurement

Surface colour on 3d display

MR and NM of brain slice
Fused display

Ack. Zuiderfeld

Ack. Robb
Exploring the volume

Ack L Bidaut
Different methods

- Point based
  - internal
  - external
- Principal axes
- Head hat, surface based

- Volume based
  - Variance
  - Mutual information

...
Aim of registration algorithm

- Finding a transform so that every point \( x, y, z \) in image dataset 1 can be mapped onto \( x', y', z' \) in image dataset 2.
Rigid and Non-rigid registration

- Rigid registration: only rotations and shifts
- Intermediate: rotations shifts and variable scale change (such as affine)
- Non-rigid: including warp, different transform for every point (or region)
Warping

Original

Rotate and Shift - Rigid

Affine

Warp - Non Rigid
Surface based registration

- Find centres of gravity
- Cast rays in both image datasets
- Measure difference is lengths of rays (L2 norm)
- Minimize distance to find match transform
Voxel based registration

- Find distance measure
  - for every voxel in image(1)
  - estimate voxel in image(2)
- compute co-occurrence matrix
- estimate ‘variance’
- Minimise distance measure
- To give transform to match image(1) to image(2)
A loop, passing though registration with various lateral shifts.
An example

Ack L Bidaut
Limited volume

Ack L Bidaut
Clustered voxel registration

- For similar data, for example CT to MR
- Some voxel map from dataset to dataset
- Some voxels do not
- Select cluster(s) of voxels that minimize

Co-occurrence Matrix

Distance measure with Displacement

How to add knowledge
Non-rigid registration

- Need for an interpolation model
  - Optic flow
  - Thin plate spline
- Need for a spatial constraint
- Need for optimisation
- Much more compute intensive than rigid registration

How to validate
Thin Plate Spline Image Warping

\[ \int \int_{\mathbb{R}^2} \left( \frac{\partial^2 f}{\partial x^2} \right)^2 + 2\left( \frac{\partial^2 f}{\partial x \partial y} \right)^2 + \left( \frac{\partial^2 f}{\partial y^2} \right)^2 \, dxdy \]

source \hspace{1cm} target \hspace{1cm} linear \hspace{1cm} TPS warped

Inspired by www-ipg.umds.ac.uk/p.edwards/warping;
Optic flow-tracking
A vector field of displacements

angle
An example- MRI breasts
Meta-data

(a) : Pre-Contrast Image  (b) : Post-Contrast Image  (c) : Subtraction Image
(d) : Motion Field  (e) : Corrected Post-Contrast Img  (f) : Corrected Subtraction Img

Ack. Hayton
Computational Parameters

- Number of voxels
- Minimisation algorithm
- Number of iterations
- Distance parameter (entropy, MI, etc)
- Number of regions of interest
- Type of interpolation
- Local constraint
- Multi-resolution speed-up

How to make it fast enough
Structure

- Segmentation
- Image registration
- Active Shape Models

- Are all different aspects of the same problem
Atlas and statistical analysis

- How to interpret the significance of an observation (target / global)
- Comparison against an atlas
- Internal reference, symmetry, time
- Need for data containing voxel values, significance range, variation in position, etc
- Building atlas requires registration, warping, normal and abnormal data

Why do we need an atlas

How to establish the databases

Why do we need an atlas?
Ack Harvard
DEFORMABLE PROBABILISTIC ATLAS

I. Brain under Analysis ($T$)

- $W_{T1}$
- $W_{T2}$
- $W_{T3}$
- $W_{TN}$

Arbitrary 3D Point

Complex 3D Volumetric Transformations

II. Archive of Normal Brains

- $A_1$
- $A_2$
- $A_3$
- $A_N$

III. 3D Probability Distribution of Matching Points

IV. Probability Value Assigned to Anatomic Point
The need for models: Analysis of functional MRI images

- Use of a model (such as factor analysis or ICA) to assess significance of change in fMRI images
- Registration of fMRI and anatomical MRI
- Registration of MRI and EEG/MEG data
- Handling of multi-modality functional image results
- In general- a branch of the development of spatio-temporal models (physically and statistically well founded)

How to develop robust models
Spatial localisation of distributed group of neurons

Stimulation: single event, block and mixed

Models of detection of fMRI activation
Models of source localisation in EEG/MEG
Spatial localisation of distributed group of neurons

Spatio-temporal model
In functional MRI

Variogramme 3D+t

lag time
0 5 10 15 20 25 30

lag distance
0 0 5 10 15 20 25 30

amplitude
0 400 800 1200 1600

Ack H Benali
An example, a set of sites with ‘significant’ activation

Ack H Benali
Cerebral plasticity (connectivity in the brain)

before resection

Activation maps

Association graphs

after resection
Towards Computer Assisted surgery: The Virtual Environment

Ack A Linney

Ack. Harvard
Applications in Cranio-facial surgery

A challenge - FEM modelling of soft tissue.

Ack. Robb
Applications in neurosurgery

- Pre-operative imaging
- Image fusion
- Applications in theatre
Surgical planning: the robot surgeon

Ack. Harvard

Ack. Zuiderfeld
Simulated biopsy

Ack L Bidaut
Image fusion in a surgical microscope

Ack Hawkes
Interaction and tools

3-D mouse and similar devices

3-D Displays
Achieving benefit: Stimulation during surgery

Limits of viable tissue during intervention

FEM models of brain to predicts brain movement
Do we need super-computers?

- Non-rigid registration
  - At present about 10-100 minutes
  - Can be made parallel
- Deformable tracking
  - At present almost real time!
- Real time signal correction
  - Requires 10x processing power
- Robot surgery
  - Smart algorithms and safer algorithms need to be developed, hence increase in computer power

How to make it cheap enough
How to make it robust/safe
GRID Computing

- Like electricity
- Distributed data
- Distributed processing

- Next generation of Internet

- Intelligence -> Exelligence
The End