UNIVERSITY COLLEGE LONDON

EXAMINATION FOR INTERNAL STUDENTS

MODULE CODE	:	**MPHYGB06**
ASSESSMENT PATTERN	:	**MPHYGB06B**
MODULE NAME	:	**Information Processing in Medical Imaging**
DATE	:	**14-Jun-11**
TIME	:	**10:00**
TIME ALLOWED	:	**2 Hours 0 Minutes**

2010/11-MPHYGB06B-001-EXAM-17

TURN OVER

EXAMINATION

MPHYGB06: Information Processing in Medical Imaging

Answer 3 questions out of 5 only.

Each question is worth 20 marks.

Answer each question in a separate answer booklet.

The marks given in square brackets at the right hand side are an indication of the marks carried by that part of the question.

Approved electronic calculators may be used.

Question 1 - Registration

1. The registration of two images A and B requires the application of a transformation $\mathbf{T}$ to A which rotates the image of 2.5 degrees with respect to the centre of the image and translates it by 3.5 pixels in the x direction and 1.8 pixels in the y direction. The origin of the image is defined at the top-left corner [0,0]. The image has a size of 256×256. What single transformation $\mathbf{T}$ (in a homogeneous coordinate system) must be applied to the image A? [3]
   The 2D rotation matrix is given by (1)

$$R = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad (1)$$

2. A subject has an MRI structural brain scan followed by PET functional brain scan. What registration algorithm would you use to align them: rigid, affine or non-rigid? Justify your choice. What level of anatomical, functional and biological correspondence can we expect? [2]

3. Entropy-based similarity measures require the construction of a joint-histogram. Describe three methods that can be used to fill a joint-histogram. [3]

4. Make a copy of the Venn diagram below, the two circles represent the entropies of two images A and B. Label the areas representing the joint entropy and mutual information . Why is it preferable to maximise mutual information rather than minimise the joint entropy in an image registration algorithm? [3]

QUESTION 1 CONTINUES, TURN OVER

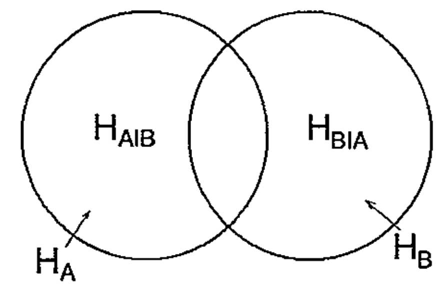

Figure 1: Relationship of image histogram entropies

5. The Free-Form Deformation algorithm for medical image registration uses a cubic b-spline deformation model. What are the advantages of cubic b-splines? Why are they preferable to a thin plate spline interpolation scheme? [3]

6. In 1D we have the following control point coordinates [10 20 30 40 50 60] and their positions [12 15 10 08 14 09]. Using a cubic B-Spline scheme, compute the position of the point of coordinate 22. Sketch the function. [4]

   The cubic B-Spline kernel is the following:

$$\beta(x) = \begin{cases} \frac{2}{3} - |x|^2 + \frac{1}{2}|x|^3, & |x| < 1 \\ -\frac{1}{6}(|x| - 2)^3, & 1 \leqslant |x| < 2 \\ 0, & |x| \geqslant 2 \end{cases} \qquad (2)$$

7. The Jacobian matrix and its determinant are widely used in image registration. Describe two applications and their motivation. [2]

Question 2 - Segmentation

1. A cardiologist wants to semi-automatically segment the left atrium (LA) from an ultrasound image (Figure 2). The left atrium is the dark area marked as LA in Figure 2. He wants the initialisation to be done by placing a small circle inside the LA. The resulting segmentation should have a closed shape with no holes.

QUESTION 2 CONTINUES, TURN OVER

Figure 2: Cardiogram

(a) Due to the characteristics of this image, the most appropriate segmentation method would be to use a snake. Why? [3]

(b) Describe the parametric model, the energy term and each of its parameters in detail. [3]

(c) Describe the greedy optimisation algorithm step-by-step. [3]

(d) What other forces can be introduced in order to force the expansion of the initial shape? Describe the characteristics of this force. [2]

(e) Can other segmentation methods be used? What would be their advantages and disadvantages? [2]

2. We want to segment the right lung from the chest CT image (Figure 3), only by selecting a point inside the organ. We want the segmentation to be able to extract the lung without including the airways (white blobs and lines inside the lungs).

QUESTION 2 CONTINUES, TURN OVER

Figure 3: Lung CT

(a) In this situation, a level-set segmentation would be ideal. Why? [3]

(b) Describe the method. [2]

(c) Why couldn't you use a snake segmentation? [2]

Question 3 - Registration

1. In the context of image registration, explain the following words:

   (a) reproducibility

   (b) accuracy [3]

   (c) precision

   (d) consistency

   (e) inverse consistency

   (f) capture range

2. Show that the general 2D rotation matrix (3) is volume preserving. [1]

$$\begin{bmatrix} x' \\ y' \end{bmatrix} \leftarrow \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad (3)$$

3. Plot the 2D points in table 1 for $[x, y, I]$. Find the missing value of I at the point $[0.25, 0.27, ?]$ using both nearest neighbour and linear interpolation. [3]

QUESTION 3 CONTINUES, TURN OVER

Table 1: Position and intensity co-ordinates

x	y	I
0.2,	0.3,	1
0.3,	0.3,	0.6
0.2,	0.2,	0.75
0.3,	0.2,	0.5
0.25,	0.27,	?

4. Define and illustrate with diagrams the terms: *target registration error* (TRE), *fiducial registration error* (FRE) and *fiducial localisation error* (FLE). [3]

5. The integral equation below (4) describes an elastic registration algorithm applied to two images A and $B(\mathbf{u})$ subject to a deformation field $\mathbf{u}$. What is the motivation for, or likely effect of each term? [3]

$$d_T = \int_\Omega [(A - B(\mathbf{u}))^2 + \alpha ||\nabla \mathbf{u}||_2^2 + (\alpha + \beta) ||\nabla \cdot \mathbf{u}||_2^2] d\Omega \quad (4)$$

6. Minimisation of the elastic cost-function in (4) requires finding the solution of a partial differential equation (PDE) at each time step. Describe two possible methods of solving the PDE. [2]

7. Dynamic contrast enhanced MRI is a type of scan in which a number of images (e.g. 20) are acquired before, during and after the injection of a contrast agent whose presence shows up brightly in T1-weighted MRI. The technique is used to assess the local vascular properties of tissue; a physiological model is often fitted to small regions of interest in order to parameterise the data. Scans typically take 20 minutes to acquire, although the acquisition time of individual images is short. Briefly discuss the need for automatic image registration when this technique is used to assess the liver (see Figure 4). Suggest some problems that may be encountered. [5]

QUESTION 3 CONTINUES, TURN OVER

Figure 4: Example T1 weighted contrast enhanced MR of abdomen

Question 4 - Segmentation

We want to automatically segment the white matter in 3D MRI data-sets obtained with a T1 protocol (Figure 5 left).

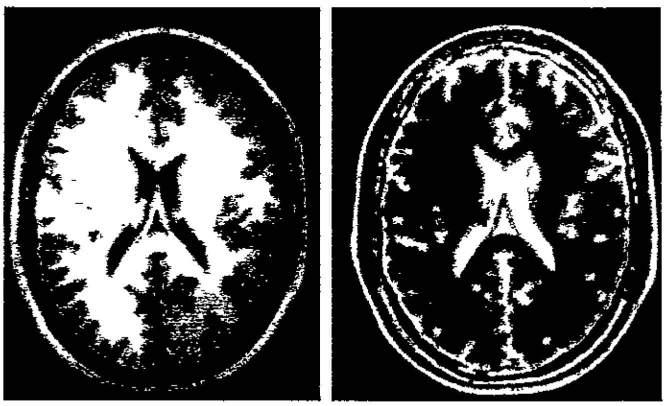

Figure 5: T1 and T2 MRI

1. The first approach to segment these images could be to use a k-means algorithm. Describe step-by-step the technique and state what problems would arise. [3]

2. In order to improve the quality of the segmentation we have now decided to use a maximum likelihood based segmentation, optimised using an Expectation-Maximisation algorithm. De- [3]

QUESTION 4 CONTINUES, TURN OVER

scribe the technique and explain what assumptions have you made regarding the intensity model?

3. Describe the optimisation procedure. What parameters are being optimised? [2]

4. Explain what will be the advantages and disadvantages of using this technique over the k-means. [3]

5. How would you compensate for the existence of a bias field using the EM framework. [2]

6. How would you improve the segmentation robustness to noise? [2]

7. If you also had a registered T2 image (right figure), how would you modify the EM segmentation in order to enable multi-spectral segmentation? Would this improve the results? [3]

8. How could you introduce anatomical knowledge about the location of the tissues? How would you change the segmentation model in order to encompass this addition? [2]

Question 5

1. The following two CUDA kernels perform a simple matrix multiplication ($C = AB$) where A is of dimensions $M \times 16$, B is of dimension $16 \times N$ and C is of dimension $M \times N$.

QUESTION 5 CONTINUES, TURN OVER

KERNEL 1

```
__global__ void multiply (float *a, float *b, float *c, int N)
{
        int row = blockIdx.y*blockDim.y+threadIdx.y;
        int col = blockIdx.x*blockDim.x+threadIdx.x;
        float sum=0.0f;
        for (int i=0; i<TILE_DIM; i++)
        {
                sum += a[row*TILE_DIM+i] * b[i*N+col];
        }
        c[row*N+col] = sum;
}
```

KERNEL 2

```
__global__ void multiply (float *a, float *b, float *c, int N)
{
        __shared__ float aTile[TILE_DIM][TILE_DIM];
        __shared__ float bTile[TILE_DIM][TILE_DIM];
        int row = blockIdx.y*blockDim.y+threadIdx.y;
        int col = blockIdx.x*blockDim.x+threadIdx.x;
        float sum=0.0f;
        aTile[threadIdx.y][threadIdx.x]= a[row*TILE_DIM+threadIdx.x];
        bTile[threadIdx.y][threadIdx.x]= a[threadIdx.y*N+col];
        __syncthreads();
        for (int i=0; i<TILE_DIM; i++)
        {
                sum += aTile[threadIdx.y][i] * bTile[i][threadIdx.x];
        }
        c[row*N+col] = sum;
}
```

Variables are marked as follows: a, b and c are pointers to global memory for the matrices A, B and C, respectively. *blockDim.x*, *blockDim.y* and TILE_DIM are all 16. Each thread in 16×16 block calculates one element in a tile of C. *row* and *col* are the row and column of the element in C being calculated by a particular thread. The for loop over i multiplies a row of A by a column of B, which is then written to C.

Which of the two kernels would perform better in terms of effective kernel bandwidth? Please explain why. Think in terms of efficient on-chip memory usage and coalesced memory access. [5]

2. Describe the main 5 memory spaces available in CUDA (global memory, shared memory, constant memory, texture memory, and registers). Discuss their relative advantages and disadvantages. [5]

QUESTION 5 CONTINUES, TURN OVER

3. What are the advantages of the pipeline and filter based design of ITK? [2]

4. What is a smart pointer and why should you use it? [2]

5. Imagine a sequence of ITK objects comprising an image reader, many filters, and an image writer, all correctly written, correclty compiling and correctly connected together.

   (a) How might the pipeline be executed? What mechanism is provided so that you can request a small subset of a full image (a region of interest) be processed rather than the full image? [2]

   (b) What system performance issues (or system limits) might you have to consider when chaining many filters together? How might you avoid these issues? [2]

   (c) What data type might you choose for (1) an image of Magnetic Resonance data, (2) an image that is a segmentation mask, (3) an image that is probability map such as from an EM output and (4) a deformation field? [2]

END OF PAPER