Engineering Tripos Part IIA, 3G4: Medical Imaging & 3D Computer Graphics, 2025-26

Module Leader

Prof Andrew Gee [1]

Lecturers

Prof Andrew Gee, Prof Graham Treece

Timing and Structure

Lent term. 10 flipped classroom interactive seminars and 6 traditional lectures. Lectures (but not seminars) will be recorded.

Aims

The aims of the course are to:

- Introduce state-of-the-art techniques for the acquisition, representation and visualisation of structured 3D data.

Objectives

As specific objectives, by the end of the course students should be able to:

- Explain the principles of operation of CT, nuclear medicine and diagnostic ultrasound and magnetic resonance imaging.
- Be aware of the advantages and risks associated with these techniques and understand the types of diagnostic problems that each can address.
- Be aware of other types of data to which segmentation and visualisation algorithms can be applied (eg. CAD models).
- Understand the different ways to represent 3D data and appreciate the advantages and disadvantages of each technique.
- Know how to extract surfaces from volumetric data.
- Be aware of the range of computer graphics algorithms and hardware used to visualise 3D data.
- Understand how surfaces can be rendered using suitable illumination and reflection models.
- Know how to visualise voxel arrays directly using volume rendering techniques.

Content

The main application area considered in the module is diagnostic medical imaging: 3D data is acquired using one of the clinical imaging modalities (e.g. CT), represented as a voxel array or segmented into surfaces, then visualised using computer graphics techniques. While medical imaging is the focus of the course, many of the techniques used to segment, represent and visualise the 3D data sets are generic and can equally be applied to other types of data, such as CAD models.

Medical Image Acquisition (flipped classroom, 5 interactive seminars, Prof Andrew Gee)

- X-rays and the Radon transform
- Tomographic reconstruction algorithms in both the spatial and frequency domains
- Emission computed tomography
- SPECT and PET
- Iterative reconstruction algorithms
- 2D and 3D ultrasound
- Introduction to Magnetic Resonance Imaging

Extracting information from 3D data (6 lectures, Prof Graham Treece)

Polygonal representations and efficient storage

- Parametric curves and surfaces
- Subdivision and display of parametric surfaces

Surfaces from sampled data

- Thresholding, morphological operators and contours
- Surface extraction - marching cubes

Interpolating sampled data

- Interpolation of isotropic data
- Distance transforms and interpolation of non-isotropic data
- Unstructured data - RBFs and Delaunay triangulation

Direct surface capture

- Laser stripe scanners
- Space encoding: the cubicscope

3D Graphical Rendering (flipped classroom, 5 interactive seminars, Prof Andrew Gee)

- Viewing systems: viewpoints and projection
- Reflection and illumination models: the Phong reflection model
- Surface rendering: incremental shading techniques, hidden surface removal using Z-buffers
- Shadows and textures
- Ray tracing
- Volume rendering
- Computer graphics hardware

Coursework

A computer-based laboratory exploring the visualization and analysis of CT data. Students write algorithms to generate slices through the 3D data set, observing the differences between linear and nearest-neighbour interpolation. They go on to fit surfaces to the data and analyse some basic geometric properties of the surfaces. Finally, they use Vulkan to visualize the surfaces from different viewpoints and under different lighting conditions, including a "fly-through" visualization mode.

Learning objectives:

- To appreciate the 3D nature of the data acquired by many medical imaging devices.
- To investigate how such data can be stored and resliced in a C++ software framework.
- To consider techniques for extracting surfaces from such data.
- To understand how surfaces can be represented by triangular meshes and stored in suitable C++ data structures.
- To analyse properties of such surfaces using basic computational geometry algorithms.
- To experiment with graphical rendering in a Vulkan framework.

Practical information:

- Sessions will take place in the DPO, during weeks 1-8.
- This activity involves preliminary work (reading the handout, around one hour).

Full Technical Report:

Students will have the option to submit a Full Technical Report.

Booklists

Please refer to the Booklist for Part IIA Courses for references to this module, this can be found on the associated Moodle course.

Examination Guidelines

Please refer to Form & conduct of the examinations [2].

UK-SPEC

This syllabus contributes to the following areas of the UK-SPEC [3] standard:

Toggle display of UK-SPEC areas.

GT1

Develop transferable skills that will be of value in a wide range of situations. These are exemplified by the Qualifications and Curriculum Authority Higher Level Key Skills and include problem solving, communication, and working with others, as well as the effective use of general IT facilities and information retrieval skills. They also include planning self-learning and improving performance, as the foundation for lifelong learning/CPD.

IA1

Apply appropriate quantitative science and engineering tools to the analysis of problems.

KU1

Demonstrate knowledge and understanding of essential facts, concepts, theories and principles of their engineering discipline, and its underpinning science and mathematics.

KU2

Have an appreciation of the wider multidisciplinary engineering context and its underlying principles.

E1

Ability to use fundamental knowledge to investigate new and emerging technologies.

E2

Ability to extract data pertinent to an unfamiliar problem, and apply its solution using computer based engineering tools when appropriate.

E3

Ability to apply mathematical and computer based models for solving problems in engineering, and the ability to assess the limitations of particular cases.

P1

A thorough understanding of current practice and its limitations and some appreciation of likely new developments.

P3

Understanding of contexts in which engineering knowledge can be applied (e.g. operations and management, technology, development, etc).

P8

Ability to apply engineering techniques taking account of a range of commercial and industrial constraints.

US1

A comprehensive understanding of the scientific principles of own specialisation and related disciplines.

US2

A comprehensive knowledge and understanding of mathematical and computer models relevant to the engineering discipline, and an appreciation of their limitations.

US3

An understanding of concepts from a range of areas including some outside engineering, and the ability to apply them effectively in engineering projects.

US4

An awareness of developing technologies related to own specialisation.

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