# Medical Computing Science at the University of Aberdeen

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### *Summary*

Computers are currently obtaining an increasingly important role in medical research, as well as in primary and secondary care, a process driven for the most part by the health−care community itself. Given the advantages linked with using computers in health−care in terms of health−care management, patient surveillance and monitoring, clinical research, medical imaging, medical decision−support and protocol−based care, it seems inevitable that the role of the computer will increase within the next five years. Currently, only a few centres in the UK possess expertise in medical computing, and there are at present no undergraduate courses offered in the UK that focus on medical computing. The University of Aberdeen could, therefore, be a major player in this field when initiatives in this direction are commenced at an appropriate time. One initiative is to offer a course in medical computing science at the undergraduate level. The course, called *Medical Computing Science* (computing science with a biomedical science focus), will be a variant of computing science and includes biomedical science and health−care topics. The aim is to attract good, scientifically oriented students. At a later stage, we may also consider starting with teaching medical computing at an MSc level. Starting with the course could be part of a broader collaborative initiative to start with a *Centre of Biomedical Computing*. The Centre of Biomedical Computing and the degree in medical computing science can only succeed when established as a joint initiative of the Faculty of Medicine and Medical Sciences and the Faculty of Science and Engineering.

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# Table of Contents

## *Introduction*

This document offers an outline of issues relevant for starting with an undergraduate course in *Medical Computing Science* at the University of Aberdeen. The exploitation of information technology and computing science in medicine and health care is known under various names: medical informatics, health informatics, health−care informatics, medical computing science, medical computer science, medical information sciences, health−care computing. The term ‘medical informatics’ is the one used most frequently internationally, evidence of which is provided by at least two textbooks with titles in which the phrase ‘medical informatics’ appears [1,2]. The term ‘health informatics’ seems to be favoured by people working in the management sciences and involved or interested in health−care organisation. The term ‘medical computing (computer) science’ seems to be preferred by those who wish to stress the links of the field with computing science. In the following, the term ‘*Medical Computing Science*’ will be reserved for the Aberdeen initiative, and not as a general descriptive term of the field, for which we will employ the term ‘medical informatics’.

To begin with, the past and future position of medical informatics in the UK is outlined from an educational perspective, including a summary of experience with medical−informatics courses in both the UK and elsewhere. Next, an indication of requested involvement of the Department of Computer Science and the Faculty of Medicine and Medical Sciences in the initiative is indicated. Finally, a tentative course structure for the planned undergraduate course in Medical Computing Science at the University of Aberdeen is presented.

## *Past and future position of medical informatics*

### *Role of information technology in health care*

Given the fact that hospitals, and health care in general, are now moving into computerisation, and that almost all university doctors, and certainly all young doctors, are now increasingly computer literate, the opportunities for medical−informatics research are becoming widespread and significant. In Scotland, the potential of the electronic patient record as a vehicle for clinical research as well as for patient monitoring and surveillance has been recognised, and there are now many initiatives, both in primary and secondary health care, which benefit from these systems. There are now also world−wide efforts to replace the paper patient record in both primary and secondary care by its electronic counterpart. Medical equipment, such as ECG and EEG equipment, is increasingly controlled by software. Furthermore, computer−based medical image analysis is rapidly evolving, as is the role of different imaging modalities in clinical decision−making. Although the extent to which clinical information systems, possibly integrated with image databases, are already in place in primary care and in hospitals varies greatly among countries and among cities within countries, it is clear that clinical information system will play a significant role in the health care of the near future. In general, health−care authorities view these developments as the way forward.

Medical informatics has been around as a subject for at least thirty years. Generally, the field has focussed on topics, such as image processing, the electronic patient record, the semantics of medical terminology, the interpretation of patient data, the security of patient data, and so on. What has changed the past few years, however, is that where previously computer equipment had limited capabilities, and was maintained centrally, now both powerful and relatively cheap personal computer equipment is available. As a consequence, whereas the storage, maintenance and distribution of medical information, including the equipment involved, were previously primarily the concern of one central organisation, medical information is now increasingly stored and maintained by those involved in its production. This has resulted in a gradual development of a distributed organisation structure, set up around the concept of the highly successful client−server architecture. Medical knowledge and data is now being accessed by those authorised, using powerful, independent client workstations. As a result, in so far as information technology is concerned, the role of the central organisation has considerably decreased. Furthermore, the decision interval as well as the development cycle have drastically reduced.

Any health−care professional who intends to produce or utilise medical information, is likely to have the facilities to do so. An increasing number of health−care professionals, including clinicians, are now eager to turn these newly offered possibilities to advantage in their daily work. There are, however, fundamental limitations on further progress in major aspects of the field due to a lack of knowledge and experience concerning advanced information technology, particularly in knowledge−based systems, machine learning and data−mining, mathematical modelling, image interpretation, natural−language systems, and intelligent agents. As clinicians and health−care authorities recognise the importance of using computers in health−care, there will be a need for a corpus of appropriately trained medical−informatics graduates, who can assist with research, development and implementation, in the very near future. It seems likely that this need will only increase in a more distant future.

## *Education in medical informatics*

As there have been previous expectations of people working in the field of medical informatics that circumstances would change, and that the computer would come to play a major role in future health care, there have been several initiatives of medical−informatics courses in the UK. Within the UK, the following previous initiatives were identified:

- BSc course in Health−care Information Systems given by the School of Computing and Mathematics at the University of Huddersfield;
- BSc in Health−care Information Systems Management, given by the Division of Computing at the University of Derby;
- MSc in Medical Informatics, taught by the Computing Science Department of the University of Glasgow;
- MSc in Medical Informatics, taught by the United Medical and Dental Schools of Guy’s and St Thomas’s Hospitals, University London;
- BSc in Medical Informatics, hosted by the Department of Computer Science at the University of Manchester;
- BSc in Heath Informatics, taught by the Centre for Measurement and Information in Medicine, City University London.

These courses all no longer exist, one may suspect because their concept did not attract sufficient numbers of students. The reasons for this may be complex, but we should consider their name (‘Informatics’ is an unknown term among secondary school pupils), or the range of topics offered (maybe too much focussed on non−clinical aspects of medical informatics).

Presently, there are just a few courses being offered, all at the postgraduate level:

- MSc in Health Information Management, University of Sunderland;
- MSc in Health Informatics, hosted by the Centre of Health Informatics and Professional Education (CHIME) , University College London;
- MSc in Medical Informatics, taught by the School of Informatics, City University, London.

There are also universities that offer a joint degree in computing and a biomedical subject, for example:

- BSc Computing/Human Biology, University of Hertfordshire;
- BSc Computer Science and Neuroscience, Keele University;
- Computer Studies with Physiology, University of Sunderland.

In the US, where the application and widespread commercialisation of technology is often several years in front of the UK and Europe, there is a strong interest in all aspects of medical informatics and computing applied to medicine. Some universities, such as North Carolina, Utah, Oregon and Stanford offer specialist Master level courses, whilst others, such as MIT and Georgia Tech, incorporate it within degree computing courses of all levels. However, all emphasise the natural progression to further research and the potential for innovation and commercialisation of products to be used in medical information processing, whether it is associated with instrumentation, medical information management, diagnosis or treatment.

Closer to home, the European scene is also developing rapidly, with medical−informatics departments at the universities of Aalborg, Freiburg, Heidelberg, Madrid, Pavia, Pireaus, Amsterdam, Rotterdam, amongst others. Research in the practical applications of integrating multiple sources at the point of clinical delivery is particularly strong, e.g. the utilisation of medical image and patient−derived data during interventions.

From the personal experience of the primary author, there are now three initiatives in the Netherlands, focussing on combining medicine and technology from the first year to the fifth year (currently the system in the Netherlands is that you have to study at least five years to be awarded the doctorandus degree; there are no intermediate degrees):

- Biomedical Technology (which also has a major medical informatics component), hosted by Eindhoven University. They can fill 90 student positions ;
- Medical Computer Science at Utrecht University. There are about 35 students each year; this exceeds the targets of Utrecht University. In each course year, 10−20% of the course comprises medical subjects, especially developed by the medical faculty for these students;
- Medical Informatics, hosted by the Academic Medical Centre of the University of Amsterdam. As this course is hosted by the medical faculty, more than 50% of the course consists of medical topics. The yearly enrolment is 40−60 students.

It therefore appears that now that the use of information technology in health care is gaining momentum, a few universities are seeing it a teaching opportunity. At the same time, the situation mentioned above does cause some concern. There is a general problem in attracting scientifically minded students, and the phrase 'Medical Informatics' does not seem to attract large numbers of students over a long period of time. In this, the evidence in the UK seems to be consistent with experience in the Netherlands. Whilst there certainly is a large group of students interested in medical informatics, many of those students would not normally opt for computing science, their first choice being subjects like medicine and medical biology. However, medical computing science could be a good second choice for them. There is experience from other vocational training programmes in technology applied to medicine, that there is a large number of potential students whose interest is primarily in a scientific field, but have a strongly held view that their training should focus on health care in its widest interpretation. For the students we wish to attract, it should be the human sciences component in medical informatics that attracts them. Historically, computing−science departments may not have been sufficiently vigorous in stressing the human−centred rationale of medical informatics; this may explain part of the failure of some of the initiatives.

By addressing the issues mentioned above, it is likely that with the joint promotion by the Medical and Science Faculties, an Aberdeen medical−computing science course could attract between 20 and 40 students. Given that the situation in a medium to long term should be more encouraging, the initial objective should be to focus on good to excellent students with a strong scientific interest. Of course, there is a minimum number of students that should be attracted to make the initiative viable. By studying medical computing science, these students would share the advantage of computing−science students of having excellent job opportunities, since the course is essentially computing science, and at the same time be accessing a field they find stimulating and rewarding.

We believe that a university that decides to promote medical informatics at this time will profit significantly in the future. A centre which now builds up expertise and a reputation in medical informatics, both in teaching and research, will play a major role in the future of medical informatics. The fact that there are only few competitors is advantageous.

### *Student profile*

Experience with medical informatics in the Netherlands (University of Amsterdam and Utrecht University) shows that the subject attracts students who have different viewpoints and attitudes than conventional computer−science student. They are socially as well as scientifically interested, and more diligent. About 30−60% of the students are women. They would not normally study computer science as a single specialism, considering the field too restricted. Some might, initially, have anticipated a medical career, only to discover that they were not well−suited to the intimate involvement with patients. There are also those who have studied medicine, but decided at a later time that pursuing medical informatics would provide a more satisfying career. In this respect, for the Amsterdam students, course components which have been satisfied by their medical training can be skipped. This may be seen as creating an alternative study path for medical students.

## *Medical Computing Science in Aberdeen*

### *Aims*

The aim of the undergraduate course in Medical Computing Science is to equip students with sufficient knowledge of and insight into the fields of medicine, health care, computing science and mathematics such that they can:

- Contribute to biomedical research, in particular in areas where the computer is used as a major tool;
- Be attractive as future employees to companies focussing on the development and production of medical equipment, like imaging workstations, patient monitoring and assessment equipment, pacemakers; or of medical software, such as clinical information systems and decision−support systems.

The Medical Computing Science course will also give the students a sufficient foundation to usefully contribute to information technology issues of health−care management, although this is not a major objective. We hope to attract good, scientifically oriented students, who feel attracted to medicine, but for some reason did not enter the medical programme. Only by attracting good students could this initiative be part of the broader initiative to stimulate biomedical computing research at the University of Aberdeen.

### *Role of the Medical Faculty*

It is impossible to start a medical computing science programme without strong links with a progressive medical faculty. Without substantial input from the medical faculty into such an initiative, it is likely to fail. The Faculty of Medicine and Medical Sciences at the University of Aberdeen includes a number of departments, which could play a major role in the initiative:

- Department of Biomedical Physics and Bioengineering (teaching of capture, presentation and interpretation of signals and images emanating from the human body);
- Department of Public Health (teaching of medical epidemiology, medical research principles, and medical statistics);
- Department of Biomedical Sciences (teaching of basic biomedical subjects, like cell biology, anatomy and physiology);
- Department of Human Pathology (teaching of human pathology, pathophysiology);
- Department of Internal Medicine (teaching of basic clinical medicine).

One of the problems is that biomedical courses taught to medical students are often not suitable for medical−computing science students. Modern biomedical courses within the medical curriculum tend to strongly emphasise the future role of students as clinicians; including medical−computing science students in this cohort could lead to a feeling of exclusion. Another problem is that having integrated the different subjects in the medical 1st year into one course, titled ‘Basic Science for Medicine (BSM)’, insufficient room is left for the necessary mathematical and computing−science subjects. As a solution to this problem, we have selected modules from the catalogue aimed at biomedical−science students, instead of the medical students.

### *Role of the Faculty of Science & Engineering*

The Department of Computing Science brings in the necessary expertise in teaching computing−science subjects, including expertise in medical−informatics research, thus providing an environment in which the students would be challenged. In addition, the department will offer the necessary computing facilities. The mathematical subjects in the course could be taught by the Department of Mathematics. Modules on human biology topics, like basic biology − including cell biology − physiology, and anatomy could be offered by the Department of Biomedical Sciences.

### Alternative study path for medical students

As Medical Computing Science is a subject that lies on the intersection of computing science and medicine, an undergraduate course in this area may also be of interest to some medical students. Some of the medical students are not suitable as a medical doctor, for one reason or the other, or might prefer to study something else than medicine at a particular stage. Medical Computing Science might be an interesting challenge for them; the medical faculty could offer their students one additional alternative route

### Opportunities for research

One of the advantages of having competent students in Medical Computing Science is that they will contribute to medical−computing research in all forms, varying from health−care research to medical decision support, model building, and medical imaging. They know the field and are familiar, albeit to a limited extent, with medical terminology. They would naturally proceed from undergraduate degree to MSc or PhD, simply because the motivation to start with medical computing was different from that of ordinary computer−science students. The existence of a *Centre of Biomedical Computing* as a joint initiative between the Faculty of Medicine and Medical Sciences and the Faculty of Science and Engineering will improve and enhance collaboration.

### Biomedical industry

There is interest from industry for medical−computing students. Philips Medical Systems, Siemens Medical Systems, and HP Medical Systems are typical. In addition, there is an expanding  market for clinical information systems, that is liley to grow further in the future. As an example, based on those assumptions of growth, the US firm Eclipsys has just started in the UK (Eclipsys provides sophisticated clinical information systems and decision−support tools to hospitals). Related areas are medical equipment manufacturers, like Medtronic, Vitatron, Leda. Where originally there was a strong emphasis on physical engineering in developing medical equipment, the role of software in such equipment is now increasing important, partly due to its versatility, and partly due to the possibilities it offers in the creation of flexible, intelligent interfaces between equipment and clinical user.

## Tentative structure of the undergraduate course

### Basic design considerations

The undergraduate course *Medical Computing Science* is intended for high quality, scientifically interested students with previous training in exact sciences. Typically, the students should feel attracted by the focus of the course on the biomedical field. As it is essential to equip these students with a robust background in computing science and mathematics, a choice has to be made from the wide variety of subjects normally covered in medical or biomedical science courses. The following design criteria could guide this choice:

- Emphasis on the biological basis of medicine, i.e. on subjects like cell biology, human genetics, physiology. The biological basis of medicine is becoming more and more important in clinical practice;

- Organ systems which, from the perspective of public health, are a frequent focus of disease processes will be covered in modules, for example, the cardiovascular system and respiratory system;
- Adherence to a system approach to medicine, starting with the principles of cell biology and physiology through a study of the structure and function of organ systems, followed by attention to disease processes and finally to clinical medicine;
- Principles of medical research, such as experimental study design, medical ethics, medical statistics and medical decision analysis should also be covered.

Furthermore, in order to be able to teach mathematically more advanced subjects such as the synthesis and analysis of medical images and the interpretation of patient−derived response, the course will include more mathematics than usually is the case with computing science.

These considerations lead to the following course structure (XX means: code not yet known; usually, these are modules that are adaptations of existing modules, or modules that have moved to another semester):

### *First year*

- Internet Information System (CS1009)
- Calculus (MA1002)
- Introduction to Medical Computing (*new 1st half session* − review of computing in decision−making, including medical artificial intelligence and expert systems, medical imaging, managing the patient, diagnosis, treatment, intervention, and rehabilitation, clinical information systems, e−healthcare, and bioinformatics)
- Algebra (MA1502)
- Introductory Programming in Java (CS1507)
- Molecular and Cell Biology (BI1505)[¶]

### *Second year*

- Data Structures and Algorithms (CS20XX)
- Introduction to Database Systems (CS20XX, replacement of CS2003)
- Anatomy courses[*]:
  - ✔ Human Cells, Tissues and Communications (AN2003), and
  - ✔ Human Functional Anatomy (AN2503)

  However, student with a good chemistry background may, with permission of the

¶ There is a timetable problem with CS1507, which is given on the same day and time as BI1505. If rescheduling of this course is not feasible, and assuming that offering an attractive course to good students is still a major objective of the BSc Medical Computing, BI1505 will need to be replaced by a *new* course. The suggested name for this course is *Basic Biomedical Science.* It may also be possible to have as an entry requirement that students have highers biology in addition to mathematics, in which case it may not be necessary to include a 1st level biology module. However, reducing the biomedical content of the course below a certain level may make it hard to impossible to convince future students that the course is really about medical computing.

* Anatomy is actually functional anatomy, so some physiology is also covered.

HoD of Biomedical Sciences, choose to follow instead two *physiology* courses[$]:

  - ✔ Human Control Mechanisms (PY 2002), and
  - ✔ Human Co−ordinated Systems (PY 2502)

- Mathematical Statistics (ST2003)
- Human Computer Interaction (CS25XX)
- Linear Algebra (MA2504)
- Computer Organisation and Interfacing (CS25XX)

### *Third year*

- Software Engineering (including software safety issues) (CS3007 − double module)
- Operating Systems (CS30XX)[¶]
- Signals and Sampling (*new −1st half session*)
- Artificial Intelligence (CS30XX)
- Discrete Methods (CS3511)
- Distributed Information Systems (CS35XX, CS4014 replacement for 3rd level)
- Medical Statistics and Sampling (MX3525)

### *Fourth year*

- Computational Intelligence (CS4017)
- Medical Image Interpretation (*new − 1st half session*)
- Pathophysiology and Clinical Medicine (*new −1st half session*)
- Professional Topics in Computing (*new − all year*)
- Three Options: Medical AI and Computing Science, or Health Sciences
- Honours Project

In the subsequent sections, a tentative content of the three new imaging and medically oriented modules is briefly described.

The following 2 modules, which would be delivered during the third and fourth year, call upon material in the MSc programmes promoted in the Department of Biomedical Physics and Bioengineering, suitably adjusted for undergraduate exposure. Certain mathematical preliminaries, such as an understanding of calculus, trigonometry and linear algebra will be needed.

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$ Physiology is actually physiology in the context of anatomy. The Physiology courses are considered to be more challenging.

¶ The module is there as a place holder, as students should follow a module focussing on Clinical Epidemiology, such as HE3012. However, this module is a 6 credit module, where there is only room for 3 credits. Half of this module covers Epidemiology, whereas the other half is about Statistics. Discussions with people of the Department of Public Health revealed that it is possible, also organisational, to only take the 3 credits Epidemiology part of the module. This is an interesting option, since without a sufficient number of biomedical and health−care topics in the 3rd level, the course may not look very convincing to future students.

### *Signals and Sampling*

The basis of most signal−based information systems implies an understanding of the sampling continuous signals to achieve their discrete counterparts. Many of the signal and image processing techniques in common use require a familiarity with processes in the real and frequency domain and the impact of noise.

- Continuous to discrete signals
- Sampling theory
- Fourier transform
- Correlation and convolution
- Structure and quantitation of noise

### *Medical Image Interpretation*

This module will introduce the image processing techniques that have been found to be useful in the interpretation of the medical image. In addition, some attention is given to the physical principles of the interaction of radiation with body tissue as a source of clinical information. Several of the techniques are equally applicable to general problems implicit in computer vision.

- Physical principles of image formation
- The system−based view of image understanding
- Image restoration and the reducing the efects of noise
- Edges, boundaries and regions
- Active models
- Rendering and interacting with the 3D image
- Multi−modality and the registration of images
- Evaluation of methodologies

### *Pathophysiology and Clinical Medicine*

This module aims to give students a basic understanding of the processes underlying disease, and also of the clinical decision−making process involved in the diagnosis, treatment and follow−up of diseases. Examples could be derived from one of the major specialties, such as internal medicine or surgery. As it is impossible to cover all types of disease process, the module should at least pay attention to disease processes that are common, such as cancer. In addition, it seems worthwhile to profit from the basis the students already have in human physiology and to focus on pathophysiology. The module also deals with issues normally dealt with in pathology, such as cell damage and repair. The following topics might be included in the course:

- cell damage and repair
- infection
- biological basis of cancer
- medical decision−making process: diagnosis, treatment, prognosis and follow−up of disease
- diagnosis, treatment and prognosis of cancer

- pathophysiology and internal medicine of fever
- pathophysiology and internal medicine of respiratory disease

This module may be based on the existing Principles of Disease module offered by the Department of Pathology.

## *Staff load*

An estimation of extra load on staff of the Department of Computing Science, the Medical Faculty, and remaining departments, based on a certain number of students entering the course, is given in the three tables below.

| | **Loads associated with Proposed Medical Computing Course** | | |
|---|---|---|---|
| | **Computing Science** | **Medical Faculty** | **Others (FSE)** |
| Year 1 | $^{1}/_{2}$ | | $^{1}/_{2}$ |
| Year 2 | $^{1}/_{2}$ | $^{1}/_{4}$ | $^{1}/_{4}$ |
| Year 3 | $^{3}/_{4}$ | $^{1}/_{8}$ | $^{1}/_{8}$ |
| Year 4 | $^{2}/_{3}$ | $^{1}/_{3}$ | |

| | **Load for 20 students per year** | | |
|---|---|---|---|
| | **Computing Science** | **Medical Faculty** | **Others (FSE)** |
| Year 1 | 10 | | 10 |
| Year 2 | 10 | 5 | 5 |
| Year 3 | 15 | 2.5 | 2.5 |
| Year 4 | $13^{1}/_{3}$ | $6^{2}/_{3}$ | |

| **Build up of Load in years of running the course**[¶] | | | | |
|---|---|---|---|---|
| | **Computing Science Department** | **Medical Faculty** | **Others (FSE)** | **Totals** |
| First | 10 | | 10 | 20 |
| Second | 19 | 4.5 | 14.5 | 38 |
| Third | 32 | 6.5 | 16.5 | 55 |
| Fourth (& Steady State) | 42 | 11.5 | 16.5 | 70 |

There is no new course development needed for the biomedical science modules incorporated in the course, except if the problem with BI1505 is not resolved. There will be one new module on medical computing in the first year offered by the Department of Computing Science. To make this initiative viable, the Department of Computing science has to initially invest a substantial effort in marketing the course. Extra personnel will be needed for this, including to compensate the organisational overhead this new course introduces. In the steady state situation, the increase in work−load of the Department of Computing Science is more than twice as much as that of the other departments. The increase in workload for the Faculty of Medicine and Medical Sciences starts after one years. To make this initiative really successful, more involvement of this faculty into the BSc course than indicated here may be necessary, as the Aberdeen Royal Infirmary is a good example of the students' future working environment. However, it is likely that this will have implications with respect to attracting new staff.

¶ Taking into account 10% drop−out on average.

## *References*

[1] E.H. Shortliffe and L.E. Perreault (eds.). *Medical Informatics: Computer Applications in Health Care*. Addison−Wesley, Reading, MA, 1990.

[2] J.H. van Bemmel and M.A. Musen (eds.). *Handbook of Medical Informatics.* Bohn, Stafleu, Van Loghum, Houten, 1997.