Introductory Lecture
UCD Biomedical Engineering Programme

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School of Mechanical and Materials Engineering
School of Electrical, Electronic & Communications Engineering
Topics

- What is Biomedical Engineering?
- Application Examples
  - Medical Devices
  - Neural Engineering
- UCD Bioengineering Programme
- UCD ME Programme Experience
I undertook this work, not only to illustrate and enrich the part devoted to mathematical demonstrations but also to enlist Anatomy and Physics into Mathematics.’

G. A. Borrelli (1679)
Bioengineering Definition (1997)

"Bioengineering integrates physical, chemical, or mathematical sciences and engineering principles for the study of biology, medicine, behaviour, or health.

It advances fundamental concepts, creates knowledge for the molecular to the organ systems levels, and develops innovative biologics, materials, processes, implants, devices, and informatics approaches for the prevention, diagnosis, and treatment of disease, for patient rehabilitation, and for improving health."

Bioengineering Definition Committee, NIH, 1997
Bioengineering - Emerging Image

Normal Ear Composition:
- Cells
- Skin
- Blood supply
- Structural element - cartilage

Inputs:
- Biology - cell growth mechanisms
- Materials - scaffold material
- Engineering - scaffold shape & manufacture

Where’s the ‘Engineering’?
IMDA (Irish Medical Device Association)
Medtech in Ireland 2012

• 50% of ventilators worldwide in acute hospitals are manufactured in Ireland
• 30 million patients rely on injectable devices manufactured in Ireland
• 33% of world’s contact lenses are manufactured in Ireland
diagnostic
hospital / homecare products
Ophthalmic
orthopaedic
vascular
contract research, development,
connected health
service
93 indigenous med tech companies
(May 2010: source Enterprise Ireland)

% companies

- >251
- 51 - 250
- 11 - 50
- <10

Number employed

Slide courtesy of IMDA
Manufacturing bases in Ireland

1. Johnson & Johnson
2. GE
3. Siemens
4. Cardinal Health
5. Medtronic
6. Baxter International
7. Philips Healthcare
8. Covidien
9. Boston Scientific
10. Abbott Laboratories
11. Becton Dickinson
12. Stryker
13. B.Braun
14. St. Jude Medical
15. 3M Healthcare
16. Zimmer
17. Toshiba
18. Smith & Nephew
19. Hospira
20. Danaher


Slide courtesy of IMDA
What role do Engineers have in Medicine?

- Fundamental Research
  - Biomechanics
  - Neural engineering
  - Biomaterials
  - New Technologies

- Design
  - Prostheses - Endo & Exo
  - Implantable Devices – stents; pacemakers, …

- Manufacture
  - Orthopaedics; Cardiovascular; Implants etc.

- Surgical Technique & Equipment
  - Computer Assisted Surgery; Medical Imaging
Prevalence of Joint Problems in General Population

Artificial joints

• Improve quality of life for patient
• Improve mobility
• Replacements:
  – Hip
    • Initial low-friction design & procedure by Charnley (1958)
    • Single most successful orthopaedic surgical procedure
  – Knee
    • E.g., Oxford knee by O’Connor
  – Other
    • Shoulder, finger, etc.
TJR - Ultimate aim of the designer:

‘a joint replacement that mimics the sophisticated function of the normal joint as closely as possible’
• Heart disease is the leading killer in the western world

• Stents production is a >$6 billion dollar per annum industry

• Ireland is home to one of the world’s largest cluster of stent design and manufacture companies

http://www.health.am/cardio/more/better-stent-surgery-stats/P2/
Fluid flow in the body
Organs-on-a-Chip

http://wyss.harvard.edu/viewpage/240/
Bioinspiration

Bioadhesives Inspired by Gecko’s Feet

Low Penetration/High Pull Off Force Needles Inspired by Porcupine Quill
Bioelectricity

- Biomedical signal and image processing
- Electrical sensors and medical devices
  - Diagnostic and Therapeutic Engineering
  - Neural Engineering
  - Rehabilitation Engineering
  - Biometrics
Biomedical Signals and Images

- Human body is made up of a number of systems (e.g. respiratory, cardiovascular, nervous system, etc)
- Each physiological process is associated with certain types of signals that reflect their nature and activities.
- These data are referred as biomedical signals and images
Bioelectric signals for:

- obtained by electrodes that record the variations in electrical potential generated by nerves cells and muscle cells.

- Single cell measurements (implanted microelectrodes measure action potential) and 'gross' measurements (surface electrodes measure action of many cells in the vicinity)

- Examples of bioelectric signals:
  - electrocardiogram (ECG) → electrical activity of the heart/cardiac cells
  - electroencephalogram (EEG) → electrical activity of the brain
  - electromyogram (EMG) → electrical activity of muscle cells
  - electrooculogram (EOG) → electrical activity of eye muscles

- Observing these signals and comparing them to their known norms, we can often detect a disease/disorders.
Neural Engineering

- Application of engineering principles to better understand the nervous system
- Development of technologies to interact with the nervous system (prosthesis, brain machine interfaces)
- Use of insight gained from studying biological systems to develop better technologies
Applications of Neural Engineering

Rehabilitation Robotics (e.g. Lokomat)

Prosthetics

Functional Electrical Stimulation

Cochlear implants

Brain Machine Interfaces

Deep brain stimulation
Stimulation configuration

Electric field around DBS electrode

+1 V

Insulating lead
Active electrode
Brain tissue

Volts
Electrophysiological data recorded during DBS surgery

High frequency (100-1140 Hz) electrical stimulation of neural centres within the brain using implanted electrodes for the treatment of symptoms of Parkinson’s disease, also being investigated for treating epilepsy, depression & obesity.
Example: Brain-Computer Interface (BCI)

- A communication system conveying messages through brain activity only [wolpaw02]

ball control using a BCI based on imagined hand movements
Principle of a BCI

1. Measurement of brain activity
2. Preprocessing
3. Feature extraction
4. Classification
5. Translation into a command
6. Feedback

Brain Imaging

Application
Why BCI Research?

• For medical applications
  BCI can be an assistive device for severely disabled people

Medical applications

- Power wheelchairs [Rebsamen07, Millan09]
- Spellers [Birbaumer99, Farwell88]
- Prostheses [Guger99, Pfurtscheller03]

Brain-controlled Functional Electric Stimulation (FES) [Pfurtscheller03]

- Treatment of ADHD (Attention Deficit Hyperactivity Disorder) [Lim10]
- Stroke Rehabilitation [Ang10]

(cf. Part 3 of this tutorial)
Non-medical applications

• Entertainment
  – Virtual Reality [Leeb07, Lécuyer08]
  – Video games [Krepki07, Nijholt10]
  – Pinball [Tangermann09]

• Mental state monitoring
  – Mental workload [Müller07]
  – Attention [Hamadicharef08]
  – Emotion [Khosrowabadi10]
Biometrics (security applications)

2D Biometrics (CCD, IR, Laser, Scanner)
- Sensors
- Extractors (Image- and signal- pro. algo.)
- Classifiers
- Negotiator (Threshold)

1D Biometrics

Decision: Match, Non-match
Engineering involved in…

• Designing stimulation system
• Manufacturing system
• Acquiring signals and Images
• Developing computer models to understand mechanisms
• Signal processing algorithm to understand the nature and changes in the physiological signal
• Map the signal to the decision part
• Improve the interface
Biomedical engineering encompasses a large number of sub-disciplines, including Biomechanics and Neural Engineering.
## Biomedical Engineering Stage 2

<table>
<thead>
<tr>
<th>Semester 1</th>
<th>Core</th>
<th>Level</th>
<th>Stage 2 Status</th>
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<tbody>
<tr>
<td>MATH20240</td>
<td>Mathematics for Engineers IV</td>
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<td>Electrical &amp; Electronic Circuits</td>
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<td>EEEN20010</td>
<td>Computer Engineering I</td>
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<td>PERS10120</td>
<td>Science of Human Performance I</td>
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<td>PHTY10040</td>
<td>Functional Anatomy &amp; Kinesiology</td>
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### Structured Elective (Electronics & Communications)

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<th>Course</th>
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<tbody>
<tr>
<td>EEEN20060</td>
<td>Communication Systems</td>
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<td>EEEN20050</td>
<td>Digital Electronics</td>
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### Structured Elective (Mechanical and Materials)

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<tr>
<td>MEEN20060</td>
<td>Mechanical Eng Design I</td>
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<tr>
<td>MEEN10020</td>
<td>Materials Sci &amp; Eng I</td>
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## Biomedical Engineering Stage 3

### Semester 1

<table>
<thead>
<tr>
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<td>ACM30160</td>
<td>Mathematics for Engineers VI</td>
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<td>EEEN30110</td>
<td>Signals &amp; Systems</td>
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<td>EEEN30030</td>
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<td>PHYS20040</td>
<td>An introduction to Physiology</td>
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<td>STAT20070</td>
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### Semester 2

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<td>Measurement &amp; Instrumentation</td>
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<td>PHTY20020</td>
<td>Applied Physics and Biomech</td>
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<td>Mechanics of Solids I</td>
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<td>MEEN20030</td>
<td>Applied Dynamics I</td>
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### Supplementary Courses

#### Structured Elective (Electronics & Communications)

- EEEN30020 Circuit Theory
- EEEN30060 Communication Theory

#### Structured Elective (Mechanical and Materials)

- MEEN20020 Manufacturing Engineering I
- MEEN30030 Mech. Eng. Design II
# ME Biomedical Engineering

<table>
<thead>
<tr>
<th>6 Modules</th>
<th>Semester 1, Year 1</th>
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<tbody>
<tr>
<td>EEME 40310 Basic Medical Sciences</td>
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<tr>
<td>EEME40460 Medical Device Design</td>
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<tr>
<td>EEME 30040 Professional Engineering (Finance)</td>
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**TWO OPTION MODULES FROM BELOW OR ELSEWHERE**

<table>
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<tr>
<th>Engineering Modules</th>
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<tbody>
<tr>
<td>EEEN40010 Control Theory</td>
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<tr>
<td>EEEN40050 Wireless Systems</td>
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<tr>
<td>EEEN30030 Electromagnetic Waves</td>
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<tr>
<td>EEEN40040 Analog and RF Electronics</td>
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<tr>
<td>MEEN30030 Mechanical Engineering Design II</td>
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<tr>
<td>MEEN40060 Fracture Mechanics</td>
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<td>MEEN20010 Mechanics of Fluids I</td>
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<td>MEEN40020 Mechanics of Fluids II</td>
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<td>MEEN30100 Engineering Thermodynamics II</td>
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<td>EEEN30160 Biomedical Signal and Image Analysis</td>
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<table>
<thead>
<tr>
<th>Modules from outside Engineering</th>
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<tbody>
<tr>
<td>PHYS20040 An introduction to Physiology: Human cells and tissues</td>
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<tr>
<td>PHYS30010 Physiology of the Cardiovascular System</td>
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<tr>
<td>NEUR30080 Neuromuscular and membrane biology</td>
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<tr>
<td>PHYC40430 Nanomechanics - from single molecules to single cells</td>
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<tr>
<td>STAT30240 Linear Models I (Statistics)</td>
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# ME Biomedical Engineering

<table>
<thead>
<tr>
<th>4 Modules</th>
<th>Semester 1, Year 2</th>
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<tbody>
<tr>
<td>EEME40470</td>
<td>Research Project / Thesis Part 1</td>
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<tr>
<td>EEME40350</td>
<td>Rehabilitation Engineering</td>
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<tr>
<td>EEME40420</td>
<td>Research Skills and Techniques</td>
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**THREE OPTION MODULES FROM THE LIST BELOW**

### Engineering Modules

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<th>Module Code</th>
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<tr>
<td>EEEN40050</td>
<td>Wireless Systems</td>
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<tr>
<td>EEEN30030</td>
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<td>EEEN40040</td>
<td>Analog and RF Electronics</td>
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<td>Mechanics of Fluids I</td>
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<td>MEEN30100</td>
<td>Engineering Thermodynamics II</td>
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<tr>
<td>CHEN40040</td>
<td>Animal Cell Culture Technology</td>
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<tr>
<td>PHYS30010</td>
<td>Physiology of the Cardiovascular System (O)</td>
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<tr>
<td>NEUR30080</td>
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<td>PHYC40430</td>
<td>Nanomechanics - from single molecules to single cells</td>
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<td>MEEN40040</td>
<td>Materials Science and Engineering III</td>
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<td>MEEN40180</td>
<td>Nanomaterials</td>
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<td>MEEN30010</td>
<td>Applied Dynamics II</td>
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<td>MEEN40070</td>
<td>Advanced Metals/Materials Processing</td>
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<td>EEEME40260</td>
<td>Professional Engineering (Management)</td>
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<td>EEEN40130</td>
<td>Advanced Signal Processing</td>
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<td>Communication Theory II</td>
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<td>EEEN40070</td>
<td>Neural Engineering</td>
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<td>EEME40340</td>
<td>Cell and tissue engineering</td>
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<td>EEME40490</td>
<td>Biomaterials</td>
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<td>PHYS20020</td>
<td>Neurophysiology:</td>
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</tbody>
</table>
• Eoin.ocearbhaill@ucd.ie
  Room 302A

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  Room 152