Biology from an EE Perspective

Rakesh K Lal

Objectives

Broad outline

How do we plan to do the course

Objectives

- Course designed to expose students with an ECE background to concepts of biology
- To see how methods from ECE can be used for modeling biological systems
  - So we would like you to approach the study of any bio-object as if you an engineer were designing it
    - Most times your designs would be far from reality but that approach will prime you for the ideas and sometimes amaze you by how robust and optimal bio-objects sometimes are!

Course structure

- Structure:
  - Roughly half the course would be devoted to reviewing biological systems
  - The rest would be for seminars in which we try to apply ECE principles for studying biological systems

How do we do this?

- Make a list of principles in ECE that are pervasive across ECE
- See if biological systems can be mapped onto those abstract ECE structures
- Check if there is any value in doing this, i.e. does the mapping allow one do something useful (such as make a therapeutic device), and especially, does the mapping have predictive value

Note

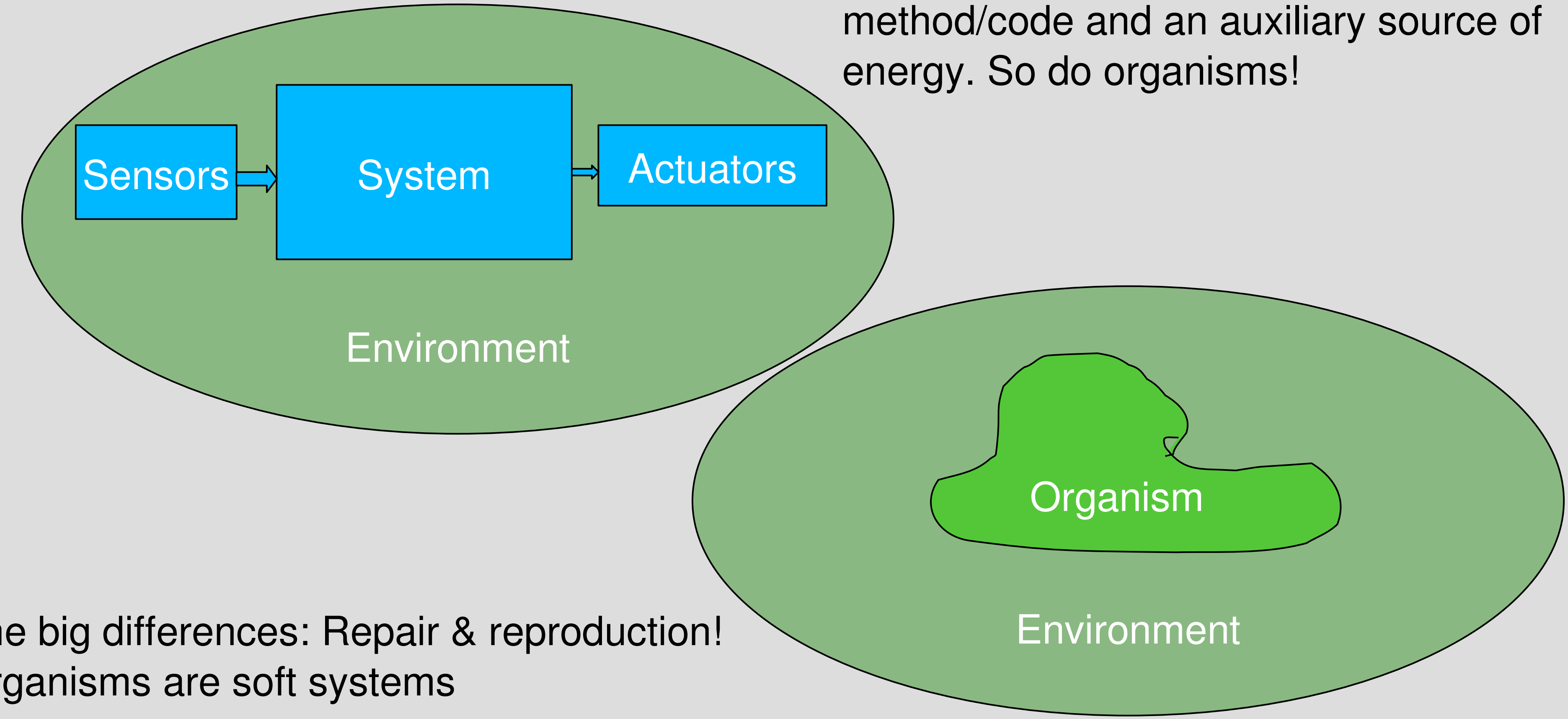
- Many kinds of electrical and computer systems are used for the study of biological processes, but we shall not look at such systems
  Mainly look at the suitability of ECE models and approaches to modeling biological systems

Cautionary note

- We know that a large bulk of ECE theory hinges on systems being causal, linear and time-invariant (essentially due to the linearity of Maxwell's equations in non-relativistic situations)
  - Sure there also are methods for handling non-linear or stochastic or time-variant systems, but they are often very problem specific though wavelet transform techniques have wide applications
- Biological systems are often non-linear and time variant, so one needs to always be on the alert to the suitability of specific models or methods

A simplistic comparison

Electrical systems respond to the environment using a control method/code and an auxiliary source of energy. So do organisms!



The big differences: Repair & reproduction!
Organisms are soft systems

ECE hierarchy of ideas

- Maxwell's equations with or without the application of Schroedinger's equations can model electrical systems
- But one normally breaks up the engineering in an hierarchical fashion and depending on one’s training one looks at systems bottom up or top down:
  - Materials
  - Devices
  - Circuits
  - Systems

Some device concepts

- Sensors, amplifiers or actuators
- Function effected by changing carriers or potentials, often both
- Use concepts of:
  - Ports & characteristics
  - Transfer function
  - Controlled sources
  - Both linear and non-linear models widely used

Some concepts related to circuits

- Analog or digital?
- For analog:
  - Frequency response – gain & bandwidth
  - Impulse response
  - Feedback and stability
- For digital
  - Input, output & transfer characteristics
  - Rise & fall times & delay
  - Feedback and racing
  - Flip-flops & clocks
  - Memory element

Some system level concepts/issues

- Finite state machines & protocols
- Communication – modulation & recovery
- Noise and error; error correction
- Information bandwidth
- Control hierarchy
- Coherence and consistency
- Robustness and redundancy
- Testability
- Energy management
- System complexity & managing design complexity

Other concepts welcome

Note: The lists of concepts in the previous slides are not exhaustive and I would welcome ideas from the class to expand that list

Biological systems

- Biological systems are far more varied than electronic/electrical systems
- However, they too respond to environmental stimuli using genetically coded, and in many organisms learned, information that helps them survive and reproduce

Biological Sensing & actuation

- Sensors & receptors:
  - Sensors for physical stimuli
  - Sensors for biochemical stimuli
  - Signal transduction,
- Signal amplifiers
  - Biochemical
  - Electrochemical
- Actuators:
  - Biochemical motors in unicellular organisms
  - Actuation in muscle systems
  - Non-mechanical actuators for signaling

Cell clusters & organ systems

- Signal transfer & regeneration
  - Biochemical (for many situations)
  - Electrochemical for organisms with a nervous system
- Feedback and control – instability
  - Biochemical, mechanical, …!!choose!!
- Local control loops at the organ level
  - Heart
  - Kidney !!!
- System wide control loops (not sure of interest)
  - Biomechanics of locomotion

Organism level signal integration and control

- Biochemical control in single celled organisms
- More complex control mediated by a central nervous system in multi-cellular organisms
  - Concept of self & state of self
  - Sensor data fusion
  - Response generation
  - Multiple organ control

  (need to select what we would like to focus on)

Lectures [1/4]

- Cells
  - Cell structure
  - Biomolecules
  - Cellular organization and function
  - Cellular energetics
- Brief introduction to biochemistry
  - Chemical transforms with cell extracts
  - Enzyme action & enzyme kinetics
  - Antibody structure and action

Lectures [2/4]

- Genes to proteins
  - DNA, RNA structure
  - Transcription DNA to mRNA
  - Translation mRNA to protein
- Biomembranes, cytoskeleton & more cell structure
  - Fatty acids, lipids and biomembranes
  - Membrane proteins and functions, transport across cell membranes
  - Internal and external membrane functions

Lectures [3/4]

- Cellular signaling
  - Receptor mediated response of cells to external stimuli – hormones & their action, receptir regulation
  - Neurons, synapses and electrical signaling
  - Modeling of action potential
- Cells to tissues & organ systems (one or two)
  - Cardiac action
  - !Nervous system or a sense organ!

Lectures [4/4]

- Cellular energetics (!)
- A bird's eye view of molecular genetics (!)
- Signaling pathways that control gene activity(!)
- Cell cycle control (!)
- Other organ systems – will need to select one or two (!)

  (need to drop some things to keep it to six weeks; so we really need feedback from the class once you begin to nibble a book in molecular biology)

Seminars

- The last four weeks would be for seminars
  - We should choose broad topics by the second week
  - Draw up reading lists
  - One person should choose to co-ordinate a seminar topic

How you should work & grading

- What I expect of the class
  - Grow knowledge regularly and systematically
  - Be inventive with applying ECE to bio
  - Take initiative in leading your seminar idea
  - Participate in the discussions
- Your expectations
- ??
- Grading
  - As suggested in flyer plus improve on that

After thoughts

- A lot of ECE knowledge is concerned with design of systems; but that is one issue I don’t want to deal with in this course
- We need to draw up a grading methodology