Challenges in Bio-technologies, Systems and Environments

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Challenges in Bio-technology, Systems and Environment

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Challenges

- Population growth
- Economic growth and change in lifestyle
- Energy demand
- Nutrient demand
- Pressure on soils
- Energy crops vs food products
Managing for Sustainability

- Sustainability = Benefits / Impacts
- Forecasting vs backcasting approach to management
System Approach to the Biochar Opportunity

- CO₂
- Biomass
- Pyrolysis
- Bio-gas
- Bio-oil
- Charcoal
- Fertiliser
- Combustion
- Upgrading
- Electricity
- Biodiesel
- Petrochemicals
- Carbon sequestration
An Immodest Proposal

A Computer Scientist Looks at Biology
Biological information today

• *Molecular Biology of the Cell (Alberts et al)*:
  – 7 pounds (3.2 Kg)
  – 1460 pages
  – 99%: English, pictures

• *Biochemistry (Voet & Voet)*:
  – 7 pounds
  – 1500 pages
  – 99%: English, pictures
Biological *and* computer systems

- HUGE!
  - Thousands or millions of components
  - Complex objects
  - MANY processes that have to go just right
  - Processes and objects have hierarchical structure
  - Especially in biology: structure is a central concept
English is lousy for describing huge systems

• Computer scientists know: English is NOT for describing big, complex systems
  – Not designed for giving precise, technical specification of systems with 1000's or 1,000,000's of interacting components
  – Not designed for giving precise specifications of structure at all levels
    • System → subsystem → class → method → code
    • Organism → organ system → organ-structure → cell → organelles → biological molecules
Computer scientists use:

- Use case diagrams
- Class diagrams
- Sequence diagrams
- Executable code

Formal descriptions

- English indispensible, but not enough
- We've learned the hard way
Role of math in physics & engineering vs. biology

- Physics, engineering, computing: structure and behavior of objects & processes of interest described with **mathematics**

- Biology: structure and behavior of objects & processes of interest described with **English and pictures**
  - No mathematics for describing the structure and behavior of the things we're interested in
    - Equations: for a few of the relationships between quantities, some of the properties
    - Behavior: single-level graphs/nets
Compare

\[ i\hbar \frac{\partial}{\partial t} \Psi(r, t) = \hat{H} \Psi(r, t) \]

vs.

- The hemoglobin molecule has four globular protein subunits. Each subunit is composed of a protein chain and a non-protein heme group. Each protein chain arranges into a set of connected alpha-helix structural segments. The connected alpha-helix segments contain a pocket. The pocket binds heme group. The heme group consists of an iron ion held in a porphyrin ring. A porphyrin ring consists of four pyrrole molecules cyclically linked together with the iron ion bound in the centre. Oxygen binds to the Fe ion. When oxygen is not bound, a very weakly bonded water molecule fills the site, forming a distorted octahedron.
Or pictures
Result

• We cannot:
  – **Quantify** structural differences
    • How similar are normal hemoglobin and sickle cell hemoglobin?
    • Degree of similarity cannot be stated mathematically
  – **Calculate** how different structures are
  – Formally **state** effects of genetic changes on structures (at multiple levels)
    • Because we can’t state or quantify the structure change formally
  – Search databases for similar structures
The immodest proposal

• **Add rigor to biology**
• Devise a mathematics for describing biological things *formally*
  – Structures (at all levels)
  – Processes (at all levels)
  – States of affairs (at all levels)
• So that huge multi-level biological systems (e.g., a cell) can be described formally, just as computer systems are now
One candidate: Entity Specifications

- Use (Name, Description) methodology to define objects, processes, generalized states (states of affairs)
  - Name: formal identifier of the entity
  - Description: formal identifiers for
    - The entity’s parts (immediate constituents)
    - The relationships between constituents
    - Any relationship, not only those mathematically definable
ES formalism

• An Entity Specification: an ordered pair \((N, D)\), where:
  – \(N\) is the formal \textit{name} of the object or process
  – \(D\) is the \textit{description} of the entity: an ordered pair \((C, R)\), where:
    • \(C = \{C_i\}\), in which \(C_i\) are the constituents
    • \(R = \{R_j\}\) is the set of n-ary relationships that must hold between the named constituents.
      – Adjacent, Distance\((x, y)\), Inside\((\text{Nucleus, chromatin})\), ...
      – Equations are relationship definitions
An example of the payoff of mathematics

\[ SD(A, B) = \sqrt{MC} \]

\[ (NA - NB)^2 + \sum_{i=1}^{MC} PD(A_i, B_i)^2 + \]

\[ \sum_{j=1}^{MT} \sum_{i=1}^{L} (R_i(ta_j) - R_i(tb_j))^2 + \]

\[ \delta \cdot \sum_{i=1}^{MC} SD(A_i, B_i)^2 \]

Structural difference between A and B
ESs: one way

• The real point: change the way math is seen by biologists
• “Mathematics is the language of physics”
• It should be the language of biology
Challenges in Bio-technologies, Systems and Environments

Biomedical Information Processing for Computer-Aided Medical Decision Making

Kayvan Najarian
Challenges in Bio-technologies, Systems and Environments

- Main Challenge: Information Integration and Processing for Computer-Aided Decision Making
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- Example I: Portable Smart Monitoring Systems

- Signal Transformation
- Filtering
- Impedence
- ECG
- Blood Pressure
- Impedence

- Filtered Heart Rate
- Filtered Blood Pressure
- Filtered Impedence
- Volume
- Respiratory Rate

- Signal Processing & Feature Extraction
- Complication Occurrence / Severity Prediction
- Demographics & Injury Information

- Report
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• Example II: TBI Decision Making Using Image Processing and Machine Learning

- Midline Shift Detection
- Quantitative Assessment of Hematoma
- Volumetric Segmentation / Measurement of Ventricles

Machine Learning for prediction of:
- ICP Range
- Outcome (e.g. Survival)
- Functional Independence Measures
- Life Saving Intervention(s)
...
Challenges in Bio-technologies, Systems and Environments

- Future challenges
  - Incorporating genomic and proteomic information in decision-making process
  - Forming effective standards for data collection and management

Kayvan Najarian’s Biomedical Signal and Image Processing Lab
Challenges in Bio-technologies, Systems and Environments?

Developing Technologies for the Bottom Billion

Considerable progress has been made over the past 50 years
• Unprecedented economic growth
• Life expectancy increase
• Agricultural product increase – A drop in food price

Yet major problems remains:
• 1.2 billion people live on less than US$ 1 per day
• 1 billion people do not have access to clean water
• More than 2 billion people have no access to sanitation
• 1.3 billion people are breathing air below the standard consider acceptable by WHO
• 800 million people food insecure
Challenges of Bio-technology - Health

Typhoid Fever

• Typhoid fever or commonly just typhoid is a common worldwide illness, transmitted by the ingestion of food or water contaminated with the feces of an infected person.

• Typhoid fever remained as a public health problem in many developing countries.

• Current diagnosis for typhoid is via the method of culture and serology (Widal test). These methods lack sensitivity, specificity and speed (more than 1 day).

• TYPHIRAPID was recently and successfully developed in USM to detect typhoid in 20 minute at a cost that is only a quarter of current technology. This has made a huge impact for the bottom billion.