A Complex Systems Approach to Important Biological Problems

by

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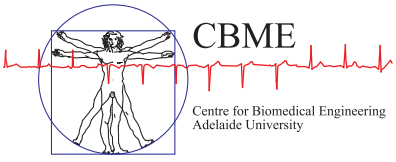

Abstract

Complex systems are those which exhibit one or more of the following inter-related behaviours:

1. Nonlinear behaviour: the component parts do not act in linear ways, that is the superposition of the actions of the parts is not the output of the system.

2. Emergent behaviour: the output of the system may be inexpressible in terms of the rules or equations of the component parts.

3. Self-organisation: order appears from the chaotic interactions of individuals and the rules they obey.

4. Layers of description: in which a rule may apply at some higher levels of description but not at lower layers.

5. Adaptation: in which the environment becomes encoded in the rules governing the structure and/or behaviour of the parts (in this case strictly agents) that undergo selection in which those that are by some measure better become more numerous than those that are not as "fit".

A single cell is a complex system: we cannot explain all of its behaviour as simply the sum of its parts. Similarly, DNA structures, social networks, cancers, the brain, and living beings are intricate complex systems. This thesis tackles all of these topics from a complex systems approach. I have skirted some of the philosophical issues of complex systems and mainly focussed on appropriate tools to analyse these systems, addressing important questions such as:

- What is the best way to extract information from DNA?
- How can we model and analyse mutations in DNA?
- Can we determine the likely spread of both viruses and ideas in social networks?
- How can we model the growth of cancer?

- How can we model and analyse interactions between genes in such living systems as the fruit fly, cancers, and humans?
- Can complex systems techniques give us some insight into the human brain?

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Statement of Originality

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by any other person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being made available in all forms of media, now or hereafter known.

3 May 2007

Signed

Date

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Thesis Conventions and Glossary

Typesetting This thesis is typeset using the LaTeX2e software. Processed plots and images were generated using Matlab 6.1 (Mathworks Inc.) and the Matplotlib module for the Python programming language. TeXShop was used as an effective interface to the TeTeX version of LaTeX.

Spelling Australian English spelling is adopted, as defined by the Macquarie English Dictionary (Delbridge 2005).

Referencing The Harvard style is used for referencing and citation in this thesis.

Genetics nomenclature The nomenclature for human genes follows the standard as published by Wain *et al.* (2002). That for bacterial genes follows the standards as published by Demerec *et al.* (1966). That for *Drosophila melanogaster* (fruit fly) follows the standards as published by Lindsley and Zimm (1992). I did make one slight alteration to the rules for nomenclature in that where they state *italics* should be used, I instead used *slanted text* in order to clarify the difference between gene names and other italicised words (for example foreign words).

Mathematical notation I have used standard mathematical notation for sets in $\mathbb{R}$, namely $x \in (a,b)$ means $a < x < b$, $x \in (a,b]$ means $a < x \leq b$, $x \in [a,b)$ means $a \leq x < b$ and $x \in [a,b]$ means $a \leq x \leq b$. I use * to denote a complex conjugate of a value, for example if $z = a + bi$, then $z^* = a - bi$. For more details, refer to Alberts *et al.* (2002).

Some definitions of key terms used in the cancer and genetics chapters:

Oncogenesis is the genetic progression to cancer.

Metastasis is the spread of tumour cells to other sites in the body.

Angiogenesis is the formation of blood vessels, which occurs naturally during growth and injury, but is a key component of tumour formation.

Apoptosis (from the Greek for "falling leaves", an example of apoptosis) is programmed cell death, whereby a genetic cascade causes the cell to kill itself quickly and cleanly, as opposed to other cell deaths, such as necrosis which occurs when cells are physically damaged.

Homozygotes are organisms that carry two identical copies of an allele (gene), whereas

Heterozygotes carry two different copies of an allele (gene) across the two homologous chromosomes.

Publications

Journal Publications

Berryman, M. J., Allison, A. & Abbott, D. (2003). Statistical techniques for text classification based on word recurrence intervals, *Fluctuations and Noise Letters*, **3**, pp. L1-L10.

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