What kind of a system is a human being? A cybernetic system?

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The central concern of this paper is to assess to what extent concepts and techniques introduced successively by cybernetics, artificial intelligence, and connectionism (i.e. neural network modelling) have proved themselves to be viable to tackle the issues that arise in modelling human behaviour. It is argued that modelling human behaviour must come to grips with 'language behaviour' and that new ideas and new probing techniques are needed to this end before we can meaningfully answer the question: 'what kind of a system is a human being?'

Cybernetics and later developments

Norbert Wiener, writing in 1948, introduced the term 'cybernetics' to cover an interdisciplinary area which he thought was of central importance in the study of 'purposive' behaviour, whether in machines or men[1].

He wrote: 'The newer study of automata, whether in metal or flesh, is a branch of communication engineering, and its cardinal notions are those of message, amount of disturbance or 'noise' – a term taken over from the telephone engineer – quantity of information, coding technique, and so on'[2].

According to Wiener, '... the problems of control engineering and communication engineering [are] inseparable, and they [centre] around .... the fundamental notion of message, whether this should be transmitted by electrical, mechanical, or nervous means. The message is a discrete or continuous sequence of measurable events distributed in time – precisely what is called a time-series by statisticians'[3].

Thus, to a group of scientists including [Wiener] 'the essential unity of the set of problems centering about communication, control, and statistical mechanics, whether in the machine or the living tissue' became obvious ... and they 'decided to call the entire field of control and communication theory, whether in the machine or animal, by the name *cybernetics*'[4].

It must be realized that in the 1940s stored-program digital computer was still an idea and not yet a realized product. Wiener, himself, had earlier – during the war-years – contributed seminal ideas to realize such machines[5]. However, because of other immediate pre-occupations, these ideas were not taken seriously and acted upon. In 1943 McCulloch and Pitts, in what was considered to be a landmark paper, had modelled a neuron by a threshold logic unit and shown that any computable function could be computed by a finite network of such 'neurons'[6]. Their threshold logic networks were the precursors of later day neural network models.

Given this Zeitgeist Wiener could speculate: '... It became clear to us that the ultra-rapid computing machine, depending as it does on consecutive switching devices, must represent an almost ideal model of the problems that arise in the nervous system ... The problem of interpreting the nature and varieties of memory in the animal has its parallel in the problem of constructing artificial memories for the machine'[7].

Another seminal idea motivating the cybernetic movement in its nascent stage was 'feedback'. In Wiener's words: 'The central nervous system no longer appears as a self-contained organ, receiving inputs from the senses and discharging into the muscles. On the contrary, some of its most characteristic activities are explicable only as circular processes, emerging from the nervous system into the muscles, and re-entering the nervous system through the sense organs, whether they be proprioceptive or organs of the special senses.'[8]

However, the early enthusiasm for modelling animal behaviour using ideas from cybernetics soon began to wane. Feedback loops in the *signal* domain, message considered as a time-series, combating noise through clever encoding of messages, recovering messages corrupted by noise through statistical filtering techniques – concepts and techniques which formed the essential underpinning of cybernetics – were soon seen to be inadequate to come to grips with 'intelligent' behaviour. Cybernetics was replaced by 'artificial intelligence (AI)' as the grand theme of human behaviour modelling. The focus shifted from modelling purposive behaviour to modelling problem-solving behaviour – considering problem-solving as the essence of intelligence. Symbol manipulation algorithms rather than signal processing techniques became the central concern of AI practitioners. Functional modelling of intelligent behaviour through these means was asserted to be a prerequisite to attempting behaviour modelling at the neurophysiological (i.e. structural) level.

After more than two decades of high-profile existence, mainstream or 'classical' AI is, in its turn, facing a keen competitor now. With the new wave created by connectionism or neural network modelling, the wheel has come full circle. Connectionism aims to construct neurophysiologically motivated models of behaviour at the 'symbolic' rather than at the 'signal' level. Thus, in some sense, connectionism tries to bridge the methodological gap between cybernetics and AI.

In the rest of this article our central concern will be to assess to what extent concepts and techniques introduced successively by cybernetics, AI, and connectionism have proved themselves to be viable to come to grips with the task of modelling human behaviour. We shall see that all the three frameworks have turned out to be inadequate in varying but fundamental ways to help us answer the question: 'What kind of a system is a human being?'. We shall argue that so far as human beings are concerned, 'language behaviour' is a central issue that needs to be addressed. New ideas and new probing techniques are needed before significant breakthroughs can be expected.

Feedback and difference reduction

To demonstrate that an extremely important factor in voluntary activity is 'feedback', Wiener offers the following illustrative example of a voluntary act most of us perform without any conscious deliberation. 'Suppose I pick up a lead-pencil. To do this I have to move certain muscles. [The selection and sequencing of these muscle movements take place without our conscious intervention.] What we will is *to pick the pencil up*. Once we have determined on this, our motion proceeds in such a way that we may say roughly that the amount by which the pencil is not yet picked up is decreased at each stage ... To perform an action in such a manner, there must be a report to the nervous system ... of the amount by which we have failed to pick the pencil up at each instant. If we have our eye on the pencil, this report may be visual, at least in part, but it is more generally kinaesthetic, or to use a term in vogue, proprioceptive....'[9]

This is a typical example of 'difference reduction' in the *signal domain*. It is easy to accept that a good deal of our 'willed actions' in the perceptual-motor domain must depend in an essential way on such difference-reduction techniques in the signal domain. But what about our 'deliberative' actions in the cognitive domain such as problem-solving? Mainstream AI practitioners argued that to cope with problem-solving in the cognitive domain, like solving logical-puzzles for example, deliberative symbol manipulation techniques are needed. Symbol manipulation cannot be handled by mere signal processing routines. Symbol manipulations imply, by definition, discrete, sequential operations. Nevertheless, it is highly significant that in 'classical' AI, general problem-solving techniques continue to be based on the 'difference-reduction' paradigm – but not any longer in the signal domain.

Difference-reduction in 'classical' AI is termed 'Means-End Analysis (MEA)'. MEA has been promoted as an underpinning for a 'unified theory of cognition'[10]. A problem delimits a problem-space consisting of a set of problem states, a set of operators that transform one state to another, and a difference function that computes differences between states. An initial state and one or more goal states (i.e. end states) are specified. Solving the problem consists in moving from state to state by invoking appropriate operators and computing the difference between the current state and one of the goal states. Operators are selected to reduce this difference. The problem-solving process stops when the goal state is reached. Difference-reduction in AI, thus, is carried out in an appropriately designed problem-space instead of in the signal space as in the case of cybernetics.

But, is problem-solving in the above sense representative of all cognitive behaviour? Consider, for example, the following kinds of behaviour:

writing a letter
writing a story
making conversation
expository discourse
intelligent tutoring
exploratory scientific research.

What could difference-reduction mean in these contexts? What is the difference that is being reduced in these cases? It is not even clear that there are well-defined problem-spaces delimiting such tasks as these. MEA would seem to have very little role to play in truly creative exploration to *discover* new knowledge.

The general problem-solving approach using MEA is best suited to tackling problems that are formulated and solved at the purely syntactic level. Puzzle-solving is an illustration of this class of problems. It is highly significant to note that all problem-solving situations in AI involve a problem-solving system grappling with *given* problem statements. In other words, search is undertaken in pre-given problem-spaces for realizing a valid path from the initial state to the goal state. But in real-life, formulating appropriate problem-spaces to tackle tasks that are encountered is the hard part of problem-solving. If an appropriate problem-space is found, half the problem is already solved. Terms such as 'discovery', 'creativity', 'originality' are used to characterize this aspect of problem-solving. 'Classical' AI has been able to provide little help to come to grips with this kind of *design-behaviour*[11].

Parallel distributed processing

A characterizing feature of the human behavioural system is specialization along several independent modalities: vision, hearing, language, motor (manipulation, locomotion, navigation). In each modality behaviour has the following attributes:

1. behaviour is creative or productive;
2. behaviour profits from past experience (i.e. the system is capable of learning);
3. behaviour relies on metacognitive skills such as planning, reasoning, reflection, etc;
4. behaviour is underpinned by skills, commonsense knowledge and specific domain knowledge.

The critical issues to resolve are these:

1. How is behaviour in each modality realized? In other words, what kinds of structures and functions underpin behaviour in each modality? What would be an adequate system-level characterization of each modality to support these structures and functions?
2. Since most interesting (i.e. intelligent) behaviour is multimodal, how is this multimodality integration achieved?

For instance, take the case of Wiener's earlier cited example of 'picking up a pencil'. If this voluntary action is jointly executed using vision and hand movements, clearly visually-given and proprioceptively-given information must be combined and coordinated to successfully achieve the end-goal of picking up the pencil. How is this intermodality coordination achieved? This problem becomes theoretically even more intractable if such coordination involves combining symbolic information (e.g. language) and proprioceptive information (e.g. hand movements). This happens, for example, in executing verbally given instructions.

Parallel distributed processing (in other words, connectionism or neural network modelling) is currently being promoted as an appropriate framework for tackling issues of the kind illustrated above. Connectionism seems an appropriate approach for modelling behaviour in the perceptual-motor modalities. However, the viability of connectionism to realize higher-level cognitive functions, or to generate complex sequential behaviour is yet to be convincingly demonstrated. Connectionism would seem to be ill-adapted to propositionizing just as 'classical' AI is ill-adapted to modelling tacit knowledge (e.g. commonsense) and perceptual-motor skills. Intermodality integration of behaviour is as difficult to tackle for connectionism as it is for AI.

Language behaviour

Wiener devotes a long chapter to 'language' in his book on cybernetics and society[12]. His central theme is: 'language, in fact, is in one sense another name for communication itself, as well as a word used to describe the codes through which communication takes place'[13]. Since, from the viewpoint of cybernetics, the theory underpinning communication is the theory of messages, as earlier discussed at the start of this article, Wiener's analysis of 'language' focuses on notions like the ensemble of all messages, the information carried by a specific message depending on its probability of occurrence, combating corruption of message by noise, recovery of the message from its associated noise, and so on.

Wiener does point out that a human being as a terminal machine of a communication network may be considered at three levels: phonetic, semantic, and behavioural. However, he has little to say about how to discuss or analyse these levels from the viewpoint of cybernetics – except to note in passing: 'I have already referred to an interesting view of language made by a cybernetically-minded philologist that speech is a joint game by the talker and the listener against the forces of confusion.'[14] Here, the concept 'game' is intended in the sense of 'game theory'.

To equate language behaviour with communication behaviour, and communication with an ensemble of messages and their associated probabilities, is to miss out on the essential and significant potentials of the language modality of behaviour. As Wiener notes, language behaviour sets human beings apart from all other animals. At the social level, communication competence is something that we may share with other animals. However, the language modality offers human beings behavioural possibilities unavailable to any other animal. *Instructability* and the capacity to *reflect* are two such behavioural possibilities.

The essence of instructability is the capacity to *tell how* to do something rather than merely *show how* to do it. The ability to reflect using language enables one to analyse one's own actions and those of others, or the state of the surrounding world as well as one's own internal states and, thus, to reason about them, draw inferences from them, and so on. Language behaviour offers, thus, both a symbolic *representational* capability and simultaneously a *discourse* capability to discourse on what has been represented by means of that very language. These are modes of behaviour unavailable to other animals.

Language behaviour enables human beings to deal with worlds distant from them in space and time and also with (imagined) possible worlds and even with counterfactual conditionals. These are essential prerequisites to constructing theories and also to perform gedanken experiments and not merely be restricted to performing experiments on the actually present, given world.

Accounting for the various potentialities of language behaviour, as outlined above, in terms of underlying structures and mechanisms confronts us with some really deep problems. Right now, neither cybernetics, nor AI, nor connectionism offers us any handle to deal with these problems in psychologically and neurophysiologically meaningful ways.

What kind of a system is a human being?

In a long letter to Wiener (dated 29 November 1946, and reproduced in full by Masani in his biography of Wiener)[15] von Neumann characterizes the human nervous system as 'the most complicated object under the sun – literally'. He is very doubtful whether any breakthroughs could be achieved by directly trying to probe the human system. However, 'if we go to lower organisms from man with 10^{10} neurons to ants with 10^6 neurons – we lose nearly as much as we gain. As the digital (neural) part simplifies, the analogy (humoral) part gets less accessible, the typical malfunctions less known, the subject less articulate, and our possibilities of communicating with it poorer and poorer in content'. von Neumann, therefore, advocates studying systems at a much earlier stage of evolution, e.g. virus or bacteriophage.

But the problem with restricting one's study to lower organisms is that while this might help us to answer some neurophysiological puzzles (especially the ones at the level of neurons, synapses, learning, memory mechanisms, and so on) it is difficult to believe that such studies would scale up to give us clues concerning higher-level cognitive behaviour. Take for example, an aspect of brain/mind which seems to provoke even the most hard-boiled scientists to indulge in wild speculations, namely *consciousness*. Supposing it turns out that the aspects of consciousness that we, as human beings, find most arresting have language behaviour as their bases. Then we are unlikely to come to grips with this problem by studying lower organisms which lack the language behaviour capability.

Crick's remarks in this context are directly relevant. He writes: 'There are, of course, few subjects more important to us than language, since it is one of the main differences between man and all lower animals. Unfortunately, for this very reason there is no suitable animal for such studies. This is why I believe that modern linguistics, sophisticated though it is, will run into a brick wall unless much more can be found out about what happens inside our heads when we talk, listen to speech or read. If language is anything like as complex as vision (which seems more than likely), the chance of unscrambling the way it really works without this extra-knowledge seems to me to be rather small.'[16]

I would like to offer the following as criteria for arriving at an agenda of research to figure out what kind of a system a human being is.

- ★ We must concern ourselves with the ordinary activities of ordinary people. For instance, complex puzzle solving, symbol manipulation, logical inference, etc., do not seem to be strong points of naive human behaviour. They are the outcomes of special education, training and practice. Also expertise in these areas would seem to require reading/writing competence.
- ★ Behaviour mediated by vision and language play a key-role in the ordinary living of ordinary people. Understanding cognition must start with understanding the nature of the mediating roles of both these modalities, and how they play these roles.
- ★ We must determine what are relevant questions to ask to arrive at this understanding.

It may be appropriate to end with another quotation from Crick. 'The present state of the brain sciences reminds me of the state of molecular biology and embryology in, say, the 1920s and 1930s. Many interesting things have been discovered, each year steady progress is made on many fronts, but the major questions are still largely unanswered and are unlikely to be answered without new techniques and new ideas .... The brain sciences have still a very long way to go ....'[17]

1. Wiener, N., *Cybernetics or Control and Communication in the Animal and the Machine*, Technology Press, MIT, 1948
2. Wiener, N , *ibid*, p 54
3. Wiener, N , *ibid*, p. 16
4. Wiener, N , *ibid*, p 19
5. Wiener, N., *ibid*, pp 10–11
6. McCulloch, W and Pitts, W., *Bull. Math Biophys*, 1943, 5, 115–133
7. Wiener, N., *Cybernetics*, p. 22
8. Wiener, N., *ibid*, p 15.
9. Wiener, N , *ibid*, p. 14
10. Newell, A., *Unified Theories of Cognition*, Harvard Univ Press, Cambridge, MA, 1990
Newell was one of the originators of Means-End Analysis For an extensive list of Newell's publications in this domain, see the memorial article 'The Research of Allen Newell', *AI Magazine*, Winter 1992, pp 19–45
11. For a more optimistic view, see Boden, M. A., *Curr Sci.*, 1993, 64, 419–433. This is a special issue on AI.
12. Wiener, N , *The Human Use of Human Beings: Cybernetics and Society*, Doubleday Anchor Book, New York, 1954, see Chapter #4
13. Wiener, N , *ibid*, p 74.
14. Wiener, N., *ibid*, p 92.
15. Masani, P R , *Norbert Wiener 1894–1964;* Vita Mathematica, Birkhäuser Verlag, Basel, 1990, vol 5
16. Crick, F., *What Mad Pursuit*, Penguin Books, London, 1990, p 152
17. Crick, F., *ibid*, p 163.

When we sought permission from Sir William McCrea he wrote back: I am only too happy for you to use it in the way you propose. However, I have revised my views on a number of problems I wrote about in the article and would have expressed things different were I to be writing at this point of time.

– Editor

Physics and cosmology: Some interactions

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Introduction

Georges Lemaître (1894–1966) was one of the founders of modern cosmology – expanding universe cosmology, as it may be called. He was *the* founder of modern physical cosmology – big bang cosmology, as it has come to be called. His ideas in this field seem to have become well-defined by 1933, although any date for their inception is harder to identify, and now, 50 years later, we are invited to commemorate this historic scientific adventure. Particularly for those of us who knew Lemaître, it is a high privilege to participate and to do so in Lemaître's own University in the Institute that bears his name.

After half-a-century of enormous developments in physics and astronomy, most of the particulars of Lemaître's model have been superceded. Probably he expected this to happen, and he did not in fact pursue them in much detail. Nevertheless the clarity and sureness with which he recognized the basic problems and the general lines along which they should be approached remain astonishing. The purpose of this paper is to sketch in some of the background to Lemaître's cosmology, to recall its main features, briefly to review the development of observational cosmology since the time when Lemaître proposed his model, and then to note some sequels to his ideas in some of the most recent models. Finally, since Lemaître sought to relate the physics and the cosmology of his day, it seems appropriate to end with some attempt to assess the present-day state of the relationship.

Lemaître's lifetime

Lemaître published his now famous first paper on the expanding universe in 1927 in Belgium. At the time he did not know that the Russian mathematician and meteorologist Alexander A. Friedman (1888–1925) had published similar work in 1922 in Germany. The names of these two men will evermore be together linked with one of the most audacious developments in physical thought. They were near contemporaries, but each lived as though the other had never been.

To notice when that was, it may help if we remember that one of the great founders of astrophysics – who must seem to most people a figure in the distant past – E. Arthur Milne (1896–1950) was actually about two years *younger* than Lemaître. By contrast, one of the great founders of geophysics, Harold Jeffreys (b. 1891), was three years *older* than Lemaître, and he is still an active scientist!

Natural philosophy

The general procedure of natural philosophy seems inevitable. *Observations* of something recognized as being observable suggest a *mathematical model* of that something; the model serves to predict the outcome of *further observations*; the actual outcome suggests an *improved model*, and so forth.

In the Newtonian approach, a model consists of the (model) system being studied + a reference frame (which models the rest of the Universe) + universal time + laws (of motion, of electromagnetism, ...) obeyed by the (model) system and regarded as unchanging with time.

Cosmology is the study of the Universe as a whole. It is therefore not amenable to the Newtonian approach. The aim of cosmology must be to construct cosmological models, not to 'discover' laws. This is the Einsteinian approach, as realized in general relativity (GR). Every GR model is a universe of its own; there is no 'rest of the universe'.

In GR any completely defined Riemann 4-space (of suitable signature) is a universe. It can be interpreted as a conceivable system of mass and stress under self-gravitation, again with no 'rest of the Universe'. This is what Einstein himself appears first to have appreciated when he wrote his paper 'Cosmological considerations on the general theory of relativity' (Einstein 1917). Of

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