Complexly Organised Dynamical Systems

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Abstract. Both natural and engineered systems are fundamentally dynamical in nature; their defining properties are causal, and their organisational and functional capacities are causally grounded. Among dynamical systems, an interesting and important sub-class are those that are autonomous, anticipative and adaptive (AAA). Living systems, intelligent systems, sophisticated robots and social systems belong to this class, and the use of these terms has recently spread rapidly through the scientific literature. Central to understanding these dynamical systems is their complicated organisation and their consequent capacities for re- and self-organisation. But there is at present no general analysis of these capacities or of the requisite organisation involved. We define what distinguishes AAA systems from other kinds of systems by characterising their central properties in a dynamically interpreted information theory.

1. Introduction

Both natural and engineered systems are fundamentally dynamical in nature; their defining properties are causal, and their organisational and functional capacities are causally grounded. Among dynamical systems, an interesting and important sub-class are those that are autonomous, anticipative and adaptive (AAA). Living systems, intelligent systems, sophisticated robots and social systems belong to this class, and the use of these terms has recently spread rapidly through the scientific literature. Central to understanding these dynamical systems is their complex organisation and their consequent capacities for re- and self-organisation. But there is at present no general analysis of these capacities or of the requisite complex organisation involved. We define what distinguishes AAA systems from other kinds of systems by characterising their central properties in a dynamically interpreted information theory.1

A satisfactory dynamical account of AAA capacity must bring together the resources of physical theory and process organisation theory into a unified theory. This presents a number of problems, not the least of which is formulating a dynamical account of process organisational notions, such as that of control.2 Whereas

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*This paper has reached its present formulation through joint discussion and it is impossible now to disentangle our individual contributions; however, one of us (JDC) has especially contributed the initial ideas for our treatment of information while the other (CAH) contributed initial ideas on systems (types, modularity). We also want to acknowledge valuable discussions with co-researcher Wayne Christensen (see references) and Bruce Penfold as well as Mark Bickhard, Jonathon D.H. Smith and Tim Smithers.
physical theory primarily involves the disposition and time evolution of energy and matter, control theory is more concerned with the organisation of interaction and information flow within a system (though its ultimate aim is controlling the disposition of matter and energy). The central problem is that a very small amount of information can alter the dynamical behaviour of a very large amount of energy and matter, as when a change of state of a bit of information in a computer can control a counterweighted dam gate to release megalitres of water. The controlling effort is minuscule compared to the effect, but it is not negligible: any control device must do some work to change its control state. It turns out that work is the common ground for informational and dynamical processes.

Most approaches to the problem since Descartes have been dualistic, treating the organisational design purely functionally (note 2) and then treating a functional design and its physical realisation separately, the only constraint being that the physical realisation can implement an appropriate functional design. Little attention is given to how functional requirements can be satisfied dynamically, in particular to the constraints that proper functioning places on the dynamics of the physical implementation. These problems are seen as primarily technical, rather than central to the nature of functionality itself. This approach has the inevitable consequence of pushing back the origin of teleology into the mists of an originating mind. In robotics and AI, one is seduced into accepting purpose as an extension of the purposes of the human designers rather than as arising intrinsically in an appropriately organised system. In cognitive science, intentionality is presupposed by restricting psychology to the study of the “cognitively penetrable” [116] and focusing it on functional explanations [46]. In biology, teleology becomes an embarrassment. Nature, through its role in selection, not only tends to take over the traditional role of God (as was recognised, though controversially, soon after the publication of Darwin’s The Origin of Species), it becomes difficult to even investigate the natural origins of purposeful creatures.

Not all control theory ignores dynamical organisation. A number of authors argue that consideration of dynamical processes can illuminate the minimal functional requirements for types of control problems. The outcome of this strategy is that many control problems turn out be much simpler than they would appear to be from a purely Cartesian computational perspective. At the same time, the strategy reveals the extent to which the Cartesian presupposition of the intentionality of the mental obscures a genuinely difficult problem: if relatively simple dynamical devices can solve apparently complex functional problems, what use are intentionality and symbolic computation? To answer this, we need to determine a class of interesting problems that either require intentionality or are advantageously solved by Cartesian reasoning. We do not address this problem here but attempt to lay a principled foundation from which it can be addressed, along with other proper questions concerning the nature of living and intelligent organisational processes, by showing where, and on what basis, those capacities which ground them (namely AAA) fit into dynamical characterisations of systems.