Chapter 20
Emergent Complexity in Conway's Game of Life

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It is shown that both small, finite patterns and random infinite very low density ("sparse") arrays of the Game of Life can produce emergent structures and processes of great complexity, through ramifying feedback networks and cross-scale interactions. The implications are discussed: it is proposed that analogous networks and interactions may have been precursors to natural selection in the real world.

20.1 Introduction

This chapter explores the emergence of complex structures and processes in Conway's Game of Life (henceforth GoL). Two very different kinds of initial position are explored. First, initial positions in which there are only a small number of state 1 ("on") cells (50, in the positions explored in detail); second, initial positions with an infinite (or at least very large) number of state 1 cells, randomly and very sparsely distributed.

Studying emergent properties in mathematically well-defined systems such as CA may be particularly useful in constructing a typology of emergence: we may be better able to say exactly what "emerges" in a particular case than we generally can in the case of real-world systems. Casti [9] defines emergence as: "system behaviour that comes out of the interaction of many participants." This can be taken to cover any interaction of lower-level entities that produces qualitatively different or novel kinds of behaviour by higher-level entities. It is useful to distinguish synchronic emergence, where interactions at one level simply maintain ongoing behaviour at a higher one, from diachronic emergence, where lower-level interactions produce new levels of organisation over time. Good examples of the former are provided by the ways cells interact to maintain the functioning of an organ such as the heart [38]; of the latter, by the "major transitions in evolution" described by [27]. This chapter is primarily concerned with diachronic emergence in what may be among the simplest systems to display the phenomenon, although the diachronic emergence discussed rests upon an underlying layer of synchronic emergence.

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A "feedback network" is a collection of components (variables or structures) linked by a network of interactions including cyclical paths, so at least some components influence themselves indirectly. In what is called here a "ramifying feedback network", some interactions produce new components, and hence new interactions. Ramifying feedback networks may be important to the emergence of complexity in both biological and socio-technical domains. Chemical evolution involving increasingly numerous and complex chemical species and reactions appears a necessary precursor to the appearance of self-replicating entities. Kauffman [23] argues that systems of polymer catalysts would pass a "critical complexity threshold" as the number of different polymers increases, past which subsystems would form where production of each member is catalysed by other subsystem members. In technological development, the identification of "components" is harder, but [13] argues that artefact-activity pairs (e.g. a bicycle and the activity of riding it) are the evolving entities. These components interact by coevolution (bicycles changed once roads were tarred) and transfer of materials and subcomponents; and although [13] does not mention the point, such interactions can give rise to new artefact-activity pairs — as improvements in steam engines and rail tracks, both developed for mining, made possible steam locomotives. Institutional systems may also provide examples: interactions between evolving institutions may reveal conflict or ambiguity, prompting the development of new institutional "components" and hence, ramification of feedback networks.

Real-world feedback networks often contain multiple layers. Complex systems are often "lumpy" [22]: despite the association of complexity and self-organisation with scale-free structures and behaviour [3], the most complex entities (organisms, ecosystems, societies) include diverse kinds of entities and processes, at multiple scales, each involving a characteristic set of processes that can to some extent be understood without considering larger or smaller scales. However, this autonomy of scales is incomplete, and events that transgress it ("cross-scale interactions") are dynamically important.

The biologically characteristic parts of an animal include organs, tissues, cells, organelles and macromolecules, each with its own characteristic range of scales, and interactions with similar entities. In social systems, we can similarly distinguish individuals, households, settlements, economic and political units of various kinds, and civilizations. The different types of entity may not fit into a single hierarchy, particular types may cover wide and sometimes overlapping size ranges, and a scale-free size distribution may cover several orders of magnitude as claimed for cities [8] and firms [1]. Nonetheless, the kind of lumpiness described, and the relative autonomy of processes at different scales may be a necessary attribute of highly complex entities [34].

Recent studies of cross-scale interactions range over plasma physics [10], oceanography [14], and the study of sepsis [36] and insect societies [35]. A model of wildfire spread is presented as an example of the production of catastrophic events by cross-scale interactions and system feedbacks in [29], with additional examples from desertification, epidemics, and structural failures in engineering. However, the most extensive work concerns ecological and social-ecological systems. The paper [30] proposes a model of "cross-scale resilience" — ecological resilience being