An Architecture for Modelling Emergence in CA-Like Systems

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Abstract. We consider models of emergence, adding downward causation to conventional models where causation permeates from low-level elements to high-level behaviour. We describe an architecture and prototype simulation medium for tagging and modelling emergent features in CA-like systems. This is part of ongoing work on engineering emergence.

Keyword: Cellular Automata, emergence, occam-pi , simulation.

1 Introduction

This paper represents part of ongoing research to establish engineering principles for complex emergent systems. Various systems require several levels of description; for example, the behavioural descriptions of individual components and of some aggregate. In an *emergent system*, there is a discontinuity in the descriptions of these various layers. For example, the low-level components might be described as changing state, whereas the system description might be in terms of the movement of patterns. The upper, system, level describes the required emergent properties.

We consider complex emergent systems, comprising many simple components. Often-cited examples of complex emergent systems include network navigation by ants (real or simulated), construction by termites, swarming and flocking, for example by birds or their simulated equivalent, boids, and cellular automata (CAs).

Engineering is a quality-enhancing activity, and is essential for the safe exploitation of emergence in nature-inspired computational systems; the engineered emergent system would be robust, with assurance of functionality and safety. In exploring emergent systems engineering, we are looking at compositionality and refinement. We start with simple emergent systems, specifically CAs, and derive more general guidance from our observations.

Elsewhere [9], we describe a system architecture to underpin engineering of complex emergent systems. We identify *three key elements*: the high-level description of the required system; the specification of the components that form

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the lowest level of the system; and the specification of the representation that integrates the first two elements. Conventional development approaches, relying on a linear reduction in non-determinism (data and process refinement; model-driven development, etc) are applicable within each element, but the low-level system components cannot be systematically derived from the system specification. The components are fundamentally different from the overall system, and cannot be described using the same language concepts.

In this paper, we explore extraction of a layered component model. The introduced layer maps from the component language towards the concepts of the emergent system. The layering approach explored here is derived from pure CA models; we deduce some characteristics of causal linkage among the system elements. We consider a system requiring emergence of specific gliders, and a case study simulating blood platelets.

2 Cellular Automata and Upward Causation

In a simple CA, such as Conway's Game of Life (GoL) [6], cell update rules and initial cell states completely determine the evolution of the CA. Emergence is detected when each cell state has a visual representation, and the repeated synchronous update of the cells reveals recognisable structures in space and time. When seeking to engineer emergence on such a CA, the three architectural elements are as follows.

1. Required emergent structures, such as gliders, described using relative motion concepts.
2. The CA, comprising many identical cell instances.
3. The representation, discretised space, to define cell neighbourhoods, and on which relative motion can be detected.

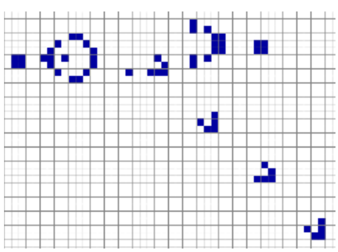

Fig. 1. A 2-D GoL Glider Gun

The CA has an *upward causal relationship* to the required emergence. For example, the upper part of figure 1 shows a GoL glider gun. In this part of the representation, we observe seemingly-random continuously-changing patterns. From the gun, a stream of gliders emerges, moving at a constant velocity, at 45 degrees from the vertical, down the screen. The glider gun is a simple result of applying the GoL rules to cells arranged in a 2-D regular grid, with a suitable arrangement of initial cell states. The high-level description of the observed behaviour of gliders does not have any role in the evolution of the CA; the described higher level behaviours are caused by the lower-level actions.