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CAPTURING EMERGENT BEHAVIOR WITHIN THE DEVS FRAMEWORK

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ABSTRACT

Analyzing complex adaptive systems is a challenging task. Nature and its governing rules do not always present clear patterns. The hypothesis of emergent properties in such systems is hard to formulate and complex to infer. In this context, a great effort is being done by the Modeling and Simulation (M&S) community towards modeling emergent behavior. Our research proposes minimal modifications into the Discrete Event System Specification (DEVS) M&S framework that brings the detection of emergent behavior into the loop of a DEVS simulation. Novel behavior is encoded into the DEVS layered structure bridging the macro and micro levels. A proof of concept was implemented for the canonical Boids model.

1 INTRODUCTION

The concept of *Emergence* has been dealt with by philosophy for centuries to understand systems in natural and social sciences. In complex adaptive systems *Emergence* can be defined as the formation of order from disorder by means of self-organization. There, novel properties appear as unexpected by just observing individual behaviors in the constituents of the system. To reason about complex systems it is essential to identify the underlying self-organizing principles that translate chaos into order.

The M&S community proposed formal approaches to deal with *Emergence* by means of e.g. Agent-based Modeling (Bouarfa et al. 2013), Grammar based models (Szabo and Teo 2015) or DEVS modifications (Zeigler and Muzy 2016). Moreover, robust simulation infrastructures for emergent behavior was recognized as a current grand challenge (Diallo et al. 2018). Our assessment of the current approaches is that they present either high implementation complexities, non-formal designs, or too abstract formulations far from practical applications. In this context our driving question is: to what extent the needs raised by the M&S of emergent behavior can be satisfied by minimal adaptations of the DEVS formal framework?

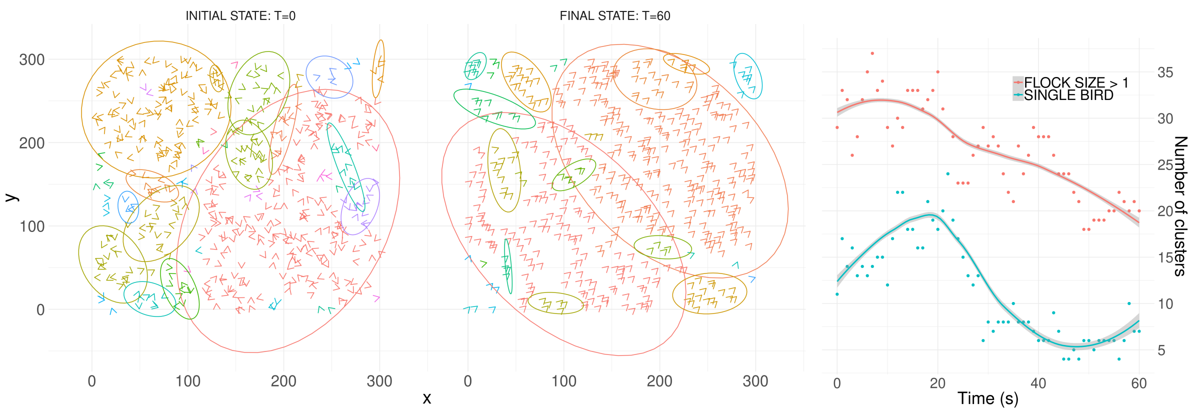
2 MACHINE-LEARNING MEETS COUPLED MODELS

We propose a slight, yet powerful modification to classic DEVS that encapsulates hierarchical emergent states within its layered structure. In our DEVS flavor, the coupled model is equipped with the ability to store aggregated states of its children models, computed with arbitrary functions. This is done via a new function F_C and state set S_C, both living in the context of the DEVS coupled model C. The communication is done via the abstract simulator data-transport protocol. By aggregating the states of the children models we can analyze emergent properties using machine-learning algorithms during runtime.

3 PROOF OF CONCEPT AND RESULTS: A DEVS-BASED BOIDS MODEL

To test our approach we implemented the canonical Boids model, an artificial life program proposed in (Reynolds 1987) vastly used to represent the emergent flocking behavior of birds. Two types of entities can be observed in the model: a *Flock* coupled model and a population of *Bird* atomic models. Each

Bird's state is described by a direction and a position. Three rules dominate the changes of direction for each Bird. *Separation* keeps Birds from colliding, *alignment* makes a Bird to point towards the average direction of the local flockmates, and *coherence* adjusts the direction of the Bird towards the centroid of its local flock. The detection of the membership of a Bird to its local flock is provided by the Flock coupled model. It is computed by accessing to observable states of its children and applying the machine-learning algorithm *Radius Neighbors Regressor*. This aggregated state belongs to the Flock coupled model's state space. Figure 1a shows the model evolution: each triangle describes the angle (direction), position (x,y) and flock membership (color). Ellipses enclose birds by flock membership for flocks with three or more flockmates. The membership function evolves over time. Local flocks emerge converging towards a shared direction pattern, going from chaos to order. Eventually the number of clusters decreases (Figure 1b).



(a) Birds and clusters in a 2D space.

(b) Evolution of clusters.

Figure 1: Evolving emergent properties. Bird orientation (left) and number of formed clusters (right).

We discussed a novel way to model *Emergent* properties within the classic DEVS Formalism, presenting a canonical case study to foresee its feasibility. Both micro and macro dynamics are captured for a set of atomic models that do not make use of explicit messaging among them, yet exhibiting *emergent* properties. As compared with the classic DEVS method, the modeling activity is greatly simplified (no explicit links exist between Birds) and therefore the number of messages handled by the abstract simulator is reduced benefiting performance. We conclude that the approach is promissory and further work is underway in order to provide the formal specification of the idea and to expand the number of case studies.

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