Proceedings of the 2017 Winter Simulation Conference
W. K. V. Chan, A. D'Ambrogio, G. Zacharewicz, N. Mustafee, G. Wainer, and E. Page, eds.

DETECTION OF EMERGENT BEHAVIORS IN SYSTEM OF DYNAMICAL SYSTEMS USING SIMILITUDE THEORY

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ABSTRACT

The existence of emergent properties, desirable or undesirable, makes a system harder to analyze and design, and requires a formal approach for detecting and reasoning about its causes and nature. The research effort presented in this extended abstract focuses on exploring emergent behaviors in a multi-agent dynamical system with the intent of reduction in complexity of detection of such unexpected behaviors. Our approach relies on the theory of similitude (or physical similarity), where the main idea is that similar behaviors occur when the values of the system variables are in a specific relation. These relations, captured using dimensionless quantities, define a hypersurface in the space spanned over the system variables, which in turn can be used to measure the distance to potential undesirable behaviors. We use similitude theory to detect undesirable emergent behaviors in swarms of UAVs (Unmanned Aerial Vehicles), treated as a complex dynamical system. Since this is a part of ongoing research, future directions are also discussed.

1 INTRODUCTION

The swarms of autonomous agents can exhibit unpredictable and often undesirable behaviors, termed *emergent behaviors*. The emergent behaviors (or emergent properties) appear when a number of simple entities (agents) operate and interact in an environment, forming more complex dynamic behaviors as a collective. Consequently, before giving control over their missions to such swarms of agents, it is necessary to establish some mechanisms to detect (if possible, predict) that an undesirable behavior is imminent. In the current work we address such issues and present techniques to detect undesirable emergent behaviors in swarms of autonomous agents. The presented technique provides lower computational complexity for detection.

2 APPROACH

Our approach is based on the theory of similitude (or physical similarity) which allows the system to be represented using dimensionless quantities. One such example of dimensionless quantity is *Reynolds number, (Re)*. These quantities help to determine different qualitative behaviors in a system, e.g., *Re* distinguishes two kinds of transition flow - laminar and turbulent. The dimensionless quantities are obtained using Buckingham's π-*theorem* (Buckingham 1914). The π-theorem states that a function $Y = F(X_1,...,X_n)$ which relates the variables of interest, can be represented in dimensionless form, $\pi_j = \frac{B_j}{A_1^{b_{j1}},...,A_m^{b_{jm}}}$, where $A_1,...,A_m$ are the dimensional quantities selected from the set $X_1,...,X_n$ (called *dimensional base*), while $B_1,...,B_r$ are the remaining quantities from $X_1,...,X_n$. Dimensional analysis provides rules and procedures for deriving the πs. Intuitively, the exponents b_{ji} are selected in such a way so that the π_js are dimensionless. The dimensionless quantities give rise to critical hypersurfaces (Kokar 1987) that separate qualitatively different behaviors in a system.

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3 SIMULATION RESULTS

We formalized an optimization problem with multi-UAV system where the goal is to control the motion of UAVs to maximize the coverage and minimize the metric of *"information age"* over the plume (targeted search area) in the environment. Figure 1 shows a NetLogo simulation snapshot of two behaviors: *desirable* - information age is minimized, and *undesirable* - emergent behavior (flocking of UAVs) causing information age to increase. We detect emergence using the metric of *variety* (Holland 2007) (calculated using dimensional quantities, shown in figure below). We compare the performance of detection using similarity versus traditional approach. The reduction in complexity is achieved by using dimensionless variables due to the reduction in dimensionality of the system space $\Re^n$, i.e., the reduction of n, by considering the impact of couplings between various dynamical systems.

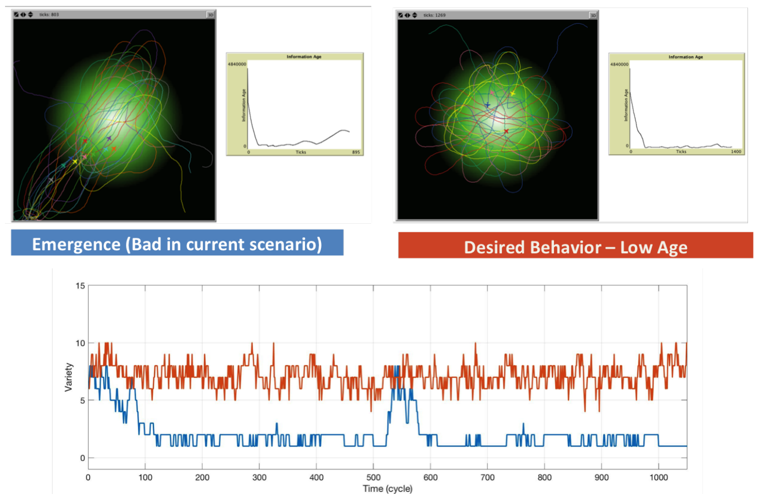

Figure 1: Emergent Behavior Detection using Variable-Based Approach (Variety Metric) with Dimensionless Quantities

4 FUTURE DIRECTIONS

The current research is work-in-progress. Our ultimate aim is to design a mechanism to control undesirable behaviors in dynamical systems. We presented our partial work in (Singh, Lu, Kokar, and Kogut 2017). Some of the existing questions in the field of emergence that are targeted in our research are: Can we develop a formal model of emergent behaviors? Since analyzing features of multi-agent systems suffers from a high computational complexity due to high dimension of the analysis space, can we find an approach to reduce the complexity of analysis? Can we detect unexpected undesirable behaviors? Can we create a complete taxonomy of emergence?

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