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Establishing Rules for Self-Organizing Systems-of-Systems

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Abstract

Self-organizing systems-of-systems offer the possibility of autonomously adapting to new circumstances and tasking. This could significantly benefit large endeavors such as smart cities and national defense by increasing the probability that new situations are expediently handled. Complex self-organizing behaviors can be produced by a large set of individual agents all following the same simple set of rules. While biological rule sets have application in achieving human goals, other rules sets may be necessary as these goals are not necessarily mirrored in nature. To this end, a set of system, rather than biologically, inspired rules is introduced and an agent-based model is used to simulate and analyze the behavior produced with various parameters. Agents represent systems and their decisions are defined by the given rule set and parameters. The environment provides a variety of time-critical missions on an ongoing basis. The effectiveness of a particular rule or set of rules is measured by a set of key performance metrics such as the rate at which missions achieve their required capabilities within a given deadline and the average time required to do so. Different rules will be compared using this criterion along with an assessment of their ability to demonstrate beneficial self-organizing behavior.

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Keywords: System of Systems; SoS; Self-Organizing; Self-Organization; Agent-Based Modeling; ABM; Emergence

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1. Introduction

Self-organizing behaviors are ubiquitous in nature, providing a large measure of stability despite widely varying and unpredictable circumstances [1]. Self-organizing behavior is differentiated from other behaviors in that it is the product of individuals making decision based on local information without external direction. This gives it resilience and scalability because the behavior is encoded in the individual and not dependent upon any particular external entity. While the benefit is obvious, the rules governing individual behavior are not.

Very simple rules have been discovered that produce complex behavior mimicking actual behavior observed in natural systems. One example of this is Schelling's Segregation Model [2] where population segregation is modeled used a single rule. This paper will define four rules for that individual systems will follow in the hopes that an effective self-organizing behavior can be demonstrated for a system-of-systems problem.

This problem has two classes of entities: systems and missions. Missions require a minimum set of capabilities in order to be carried out and have a deadline for acquiring these capabilities before the mission is failed. There are various types of missions, each requiring a different set of capabilities. Systems provide the capabilities required by missions. There are multiple types of systems, each providing a different set of capabilities, although they all move at the same speed. Simulations using various weightings of the four rules will then be carried out and the results analyzed. The parameters of the rule set are the weights given to each rule in the set.

2. Approach

An appropriate approach for this type of problem is spatial agent-based modeling [3]. NetLogo [4] was chosen as the modeling software because of its ease of use and excellent reputation. The missions have the following states: inactive, activated, go, and failed. Missions in the inactive state do nothing until activated at random. In the activated state, they signal their capability needs, location, deadline, and committed systems. If the required capability mix is achieved, then the mission transitions to go and then back to inactive after the mission is complete. If the deadline expires before these capabilities are acquired, the mission fails and transitions back to inactive. The systems have four states as well: idle, enroute, committed, and engaged. Systems are idle when they have not decided on a mission. An enroute system has decided on a mission and is moving towards it. A committed system is one that has reached its mission and is can no longer change missions until this one finishes or fails. An engaged system is one that is participating in a mission that is now in a go state. The four rules that systems use for their decision making, that decision being which mission to choose, are:

- Mission popularity (measures likelihood of mission gaining required assets),
- Distance to mission (measures time commitment required to reach a mission),
- Contribution to mission (measures degree to which a mission can make use of a system), and
- Urgency of mission (measures time remaining before mission failure).

The first rule, mission popularity, is the number of systems assigned to each mission that are in a committed state which is then normalized by dividing by the total number of systems. The second rule, distance to mission, is the Euclidean distance from the agent to the mission rendezvous point normalized by dividing by the longest distance possible. The third rule, contribution to mission, is the number of capabilities supplied by the system that match those required by the mission and is normalized by dividing by the number of capabilities possible. The fourth, and final, rule is mission urgency which is defined as the time left until a mission's deadline expires and is normalized by dividing by the maximum mission deadline.

There is a stochastic element involved as well. A system in the idle state will decide to pursue a mission that it has decided upon with the probability given in the accept rate. A system can decide to pursue a different mission while enroute with a probability defined as the reconsider rate. The stochastic variables are intended to prevent similar systems from always choosing the same mission and becoming redundant. Finally, the weights applied to each rule are restricted to the range $[-1, +1]$, which allows a rules to act as its own antithesis with a negative weight or to be eliminated when its weight is zero. These weights, along with accept and reconsider rates, are the only parameters of the rule set and the weights are known as the rule affinities. When only one rule is non-zero, the magnitude of its