Chapter 2
Temporally Autonomous Agent Interaction

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ABSTRACT
This work reflects the results of continuing research into “temporally autonomous” multi-agent interaction. Many traditional approaches to modeling multi-agent systems involve synchronizing all agent activity in simulated environments to a single “universal” clock. In other words, agent behavior is regulated by a global timer where all agents act and interact deterministically in time. However, if the objective of any such simulation is to model the behavior of real-world entities, this discrete timing mechanism yields an artificially constrained representation of actual physical agent interaction. In addition to the behavioral autonomy normally associated with agents, simulated agents must also have temporal autonomy in order to interact realistically. Intercommunication should occur without global coordination or synchronization. To this end, a specialized simulation framework is developed. Several simulations are conducted from which data are gathered and we subsequently demonstrate that manipulation of the timing variable amongst interacting agents affects the emergent behaviors of agent populations.

INTRODUCTION
In this paper, previous simulations (Conover & Trajkovski, 2007; Conover, 2008b) involving passively interacting temporally autonomous agents are expanded to accommodate active agents which directly communicate — albeit in a primitive manner. Throughout the sections of this paper, several agent activation models are explored. In each model, agents exchange “beliefs” via simple messages which are reflective of an agent’s internal state. Loosely speaking, it is the goal of any given agent to “convince” neighboring agents to adopt the given agents currently held belief (internal state). Though agents may take on many states during a simulation, each agent communicates only its currently active state only with its spatially embedded neighbors.
The first model to be discussed is divided into two distinct subtypes. The first subtype, discussed in the next section, is a direct extension of our previously studied “Conway” Game of Life models (Conover, 2008a; Conover 2008b); but agents respond to events generated by neighbors rather than vivificating autonomously. The second subtype, discussed in the third section, is a completely new model based upon temporally variant belief interaction. We have found that both subtypes display interesting and unique behavioral characteristics.

MESSAGE ACTIVATION MODEL

In this mode, each agent begins in a random Boolean state conforming to the basic “Conway” life/death (active/inactive) Game of Life rules (Gardner, 1970). As with the threaded model discussed in previous work (Conover, 2008a), the agents behave autonomously within a global mean vivification delay time $d_m$ of 500ms with delay variances $d_v$ chosen to produce $d_v / d_m$ ratios $r_{vm}$ ranging from 0.0 to 2.0. However, instead of agents simply examining their neighborhood at intervals which are independent of the environment, the agents trigger the vivification of their neighbors by sending event messages. To maintain temporal autonomy, each agent periodically queries an internal message queue (once per vivification cycle) for the presence of pending notifications received from other agents. The agent adopts a new state from the statistical mode derived from the queued messages as well as its current state. If an agent is inactive, it cannot become active until it receives a notification from an active neighbor. Only active agents are capable of sending messages to other agents. When any given agent vivificates, it determines the state of its own environment and sends notifications to all neighbors, if it becomes or remains active. An agent will only send one message to each of its neighboring agents once per vivification cycle regardless of how many messages are in the queue. Once the vivification cycle completes (all neighbors have been notified), the sending agent clears its message queue and again awaits new messages from neighboring agents.

The primary focus of this section is an exploration of the average population density of active agents and average age of the agents as a given trial progresses. However, in this section, the number of messages received by each agent between vivifications is considered. A summary of the data gathered in the first set of message based activation trials is shown in Table 1, ordered by $r_{vm}$. Other values include the average population density $pd_{avg}$, the population’s average age $age_{avg}$, the average number of messages received per agent $msgs_{avg}$, and the standard deviations $\sigma_{pd}$, $\sigma_{age}$, $\sigma_{msgs}$, of data in each sample set grouped by $r_{vm}$.

Figure 1 shows the data pertaining Message Activation Ratios as they relate to population densities of each agent population. Specifically, population age and density versus $r_{vm}$ are both illustrated in Figures 1a and 1b. Figure 1c shows the average number of messages received per agent per vivification. The lighter line in each of these is a simple cubic regression plot. One curiosity depicted in these graphs is the absence of the smooth curves generated by the models examined in the “passive models” described in previous research (Conover, 2008a; Conover 2008b).

A few points of interest are immediately apparent in this data: First and foremost is that the average number of messages received and the average population age curves are nearly identical in shape. This is mirrored by the similarity of the respective standard deviations (shown with the data in Table 1). The standard deviations were computed individually for each set of five trials for each $r_{vm}$. A close examination of this table