Chapter VI
A Simulation of Temporally Variant Agent Interaction via Passive Inquiry

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ABSTRACT

This chapter presents a description of ongoing experimental research into the emergent properties of multi-agent communication in "temporally asynchronous" environments. Many traditional agent and swarm simulation environments divide time into discrete "ticks" where all entity behavior is synchronized to a master "world clock". In other words, all agent behavior is governed by a single timer where all agents act and interact within deterministic time intervals. This discrete timing mechanism produces a somewhat restricted and artificial model of autonomous agent interaction. In addition to the behavioral autonomy normally associated with agents, simulated agents should also have "temporal autonomy" in order to interact realistically. Part I of this two-part series focuses on an exploration of the effects of incremental migration of John Conway's "Game of Life" form a simple cellular automata simulation to a framework for the exploration of spatially embedded agents.

INTRODUCTION

When we discus agents, we use the term *agent* as it is generally described in common literature (Wooldridge, 2002); (Ferber, 1999). Primarily, an agent should have attributes of autonomity, intentionality, and proactivity. However, in addition to the behavioral autonomy normally associated with agents, we add the concept of temporal autonomy to give agents the freedom to "activate" without global coordination. This includes the ability to send messages to other agents at any time, and respond to the environment (including other agents) in variable time. In our previous work, we discussed the effects of *temporal asynchronicity* on a modified version of John Conway's famous *Game of Life*. This chapter extends that research to include message-based interaction of simple agent swarms and revisits previous research into a temporally asynchronous version of *Game of Life* where relevant (Conover &

Trajkovski, 2007). By "temporal asynchronicity", we mean that agents are free to send messages or respond to their environment independently of any globally coordinated synchronization mechanism.

Experiments with a number of different models of interaction show that the variability of the rate at which certain groups of agents exchange information affects the overall state of a swarm of agents. However, these effects are not necessarily intuitively predictable. In our research, we look at the effects of this variability on the average age of agents in an environment, overall population density, and the effect of message exchange leading to unity and/or diversity of simple agent "beliefs". Here we describe the research and results behind the development of a highly multi-threaded Java™ application for the simulation of swarms of "temporally variable" autonomous agents. We will also demonstrate that measurable differences can be observed and reproduced in various agent "swarm" type simulations by varying the asynchronous variably of timing in clusters of autonomous agents.

We start by classifying two distinct behavioral models for spatially embedded swarms of agents, with each model being examined as a collection of secondary sub-models. By "spatially embedded", we mean that the agents are constrained in space within a finite *world*. Each agent communicates with a fixed set of neighboring agents throughout the duration of a simulation. The two primary behavioral groups are differentiated as follows:

- **Passive inquiry:** Each agent examines the state of its environment at periodic time intervals and updates its own state based upon an examination of agents in its immediate vicinity.
- **Belief promulgation:** Each agent periodically communicates with neighboring agents by sending simple belief messages. The recipients of the messages alter their own states based upon the type and strength of the messages received.

As an initial experiment, we have chosen to examine the effects of temporal autonomy on the well known *Game of Life* (Gardner, 1970). Though the *Game of Life* is a simulation normally associated with cellular automata (Wolfram, 1994), diverse applications have been found in theoretical fields such as number theory and game theory (Berlekamp, Conway, & Guy, 1982), computation (Mitchell, Crutchfield, & Hraber, 1994), as well as in applied fields such a materials science (Varde et al.., 2004). For our purposes, it is reasonable to view this same simulation as a rectangular grid of *agents* where each agent is capable of limited communication with neighboring agents. Agents may be considered *active* (on) or *inactive* (off) based upon the rules of the "game" as opposed to agent states representing "live" or "dead" cells as with the *Game of Life*. Many agent simulations treat agent behavior as state changes that occur in accordance with a global clock or similar timing mechanism (Hautamäki, 1997)(Fonseca, Griss, & Letsinger, 2002)(Bordini et al.., 2006). However, if we wish simulated agents to be truly autonomous, then each agent needs the additional freedom of acting autonomously in time.

The introduction of *Temporal Autonomy* into the *Game of Life* provides a reference model for the exploration of non-deterministic temporal variability within an existing, well studied, and deterministic simulation. Though some work has been done in examining the effects of synchronous versus asynchronous updating in the *Game of Life* (Blok & Bergersen, 1998)(Schönfisch & Roos, 1999), little work has been done studying these effects as they pertain to agent interaction. To enable exploration of temporal autonomy in agent interaction, we have written a small simulation environment in Java which alters the traditional *Game of Life* behavior. In this environment each cell in the world may exist within its own independent thread of execution. Though several techniques could be employed to simulate this multi-threaded behavior, the ease of thread creation and manipulation in Java makes a truly multithreaded approach practical.

Subsequent sections of this chapter provide an overview of our continued work in the area of agent interaction in "temporally asynchronous" environments and outline preliminary results. First, we provide a brief overview of the simulation environment, and then outline the simulation methodologies and results. The experiments are divided into two distinct sets: In the first set, the *Game of Life* model