The Greek Miracle: An Artificial Life Simulation of the Effects of Literacy on the Dynamics of Communication

A Thesis

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Abstract

The period of time during the fourth and fifth centuries B.C., when the Greek society moved out of the Dark Ages and into the "golden" period of so many great scientific, philosophical, and literary achievements, has often been called the "Greek Miracle." Many historians claim this cultural shift of Greece was "profoundly influenced" by the introduction of alphabetic literacy to the population.

After discussing this impact from a humanities standpoint, an artificial life simulation is used to investigate the dynamics of communication found in both a primarily oral population as well as a literate one. In each simulation, we find complex systems known as simorgs, or simulated organisms, whose behavior is determined by a transition table. The communication found in both simulations is compared in terms of different parameters such as population size, interconnect probability, and transition table entries. In the literate simulation, we find more activity and longer cycle lengths.

One powerful parameter that we focus much of our attention on is the lambda parameter, a parameter first investigated by Christopher Langton in his research on the emergence of computation in complex systems. The lambda parameter is used to create different levels of behavior complexity. As we increase this value, we observe similar patterns of behavior. In particular, we find a region of "complex structure" between orderly and chaotic behavior which exhibits the

greatest potential for the storage and transmission of information. We infer that it was in this region that the Greek culture reached such lofty heights after finding the perfect balance between order and chaos. We are not able to infer that the alphabet was the sole of primary cause of this miracle however after finding a similar “explosion” of activity as we enter the region of complexity. However, we conclude that this was most likely the area where the Greek Miracle occurred and should be the area of focus for future investigation to possibly determine the exact cause of the cultural shift we saw in ancient Greece.

Finally, we attempt to model two separate populations — one which uses an alphabetic script and another which uses a hieroglyphic one. Alphabetic Literacy is defined to be achieved at ten times the rate of hieroglyphic literacy due to its simplicity and flexibility. As a result, we find alphabetic literacy spreading throughout the population at a much faster rate and close to a 100% literate population in that region “on the edge of chaos.”

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Chapter 1

Introduction

1.1 Motivation

The original motivation for this thesis stems from the work several years ago by Dr. Bruce J. MacLennan and archeologist J. Penny Small on the effects of literacy and whether it played as important a role in bringing about The Greek Miracle as historians have claimed. They coined the name *SimLit* (for Simulating Literacy) for their work since they were setting up a simulation in an artificial life environment to investigate the effects literacy may have.

The work of Christopher Langton, director of the artificial life program at the Sante Fe Institute in New Mexico, in his paper "Computation on the Edge of Chaos" also played a part in the motivation behind this thesis. In his paper, Langton finds similarities in the behaviors of computations and physical systems near phase transitions. In particular, he found a very interesting region on the edge of chaotic behavior which provided the optimal conditions for the transmission, storage, and modification of information.

Dr. MacLennan brought his research to my attention in the fall of 1993. I became very interested in the subject and began working with him on it the following semester. We kept the original goals of *SimLit* although, we modified the original simulation.

The original literacy simulation model had been set up along the same lines as Dr. MacLennan's evolution of communication experiments and focused more on the origins of literacy. We decided to design an experiment more similar to Langton's. Such an experiment would allow us to examine the effects of literacy and possibly find a critical point (phase transition) that would increase the number of literates to a stage of sufficient numbers (the edge of chaos), thus allowing the Greek Miracle to emerge. This experiment would simple to design and flexible. Also, it should do more interesting things than the original model.

In order to truly investigate the effects literacy may have on a population, one needs to study all the factors at work in a non-literate or oral community; we began with a very simple, new artificial life model of oral communication and built up from there.

1.2 Objectives

The objective of this thesis is to investigate and compare in terms of different parameters the general properties of communication found in artificial life simulations of oral populations with those found in literate populations. We are viewing communication as a "complex system" and attempt to find some region on the "edge of chaos" as Christopher Langton did where computation emerges and the transmission of information is at its maxim. The existence of such a region will allow us to make some generalizations about the effects of literacy. We also want to explore and compare an alphabetically literate population with one which is hieroglyphically literate.

1.3 Overview

This thesis consists of six chapters. In chapter 2, we research the Greek Miracle and explore exactly why the Greek alphabet has been referred to as a "piece of explosive technology." In Chapter 3, we explain the setup in the artificial life environment we will be using and all the parameters being studied. Chapter 4 looks at the results we found investigating changes in our different parameters. Chapter 5 details our simulation of a literate community and our comparison between alphabetically and hieroglyphically literate populations. In Chapter 6, we look at the conclusions that can be drawn from our work and consider some additional experiments that could be investigated in the future. Following Chapter 6, an appendix contains the source code for the artificial life simulation of an alphabetically literate community. But before we get into the details of the simulation of the Greek Miracle, we need to explain exactly what artificial life is all about.

1.4 Preliminaries

During the time I was working on my thesis, there was one question more than any other that continually popped into my mind and that was "Is this life?" That is, can these simulated organisms we have created in the computer be classified as life forms. If so, what rights do I have? Is it murder if I terminate the program?

Many scientists during the past two decades working in this brand new discipline known as artificial life have asked themselves the exact same questions after creating computer based life systems in which individuals can live, die, reproduce, and compete for survival. The question of whether or not this can be defined as "life" has become one of the central questions of this discipline.

Artificial Life, by definition, is a field of study "concerned with human-made systems that exhibit behaviors which are more or less characteristic of natural living systems" [24].

One of the nice things about artificial life is that it allows us to create a "silicon world" where we can investigate the behavior of simulated organisms without worrying about studying them in their "messy" natural environment [18, 22]. Two other important advantages are that evolution can occur at a much quicker rate and identical populations can evolve under a variety of different parameters [19].

When artificial life is used to study the behavioral and social aspects of an organism in a simulated environment, we define it as synthetic ethology [19]. Synthetic ethology is often confused with the term simulation. Our experiment should essentially be termed a simulation since we are modeling complex systems whose behavior is programmed. Synthetic ethology focuses on many simple systems which are not programmed to behave in a certain manner.

Chapter 2

The Role of Alphabetic Literacy in the Greek Miracle

2.1 Introduction

During the fifth and fourth centuries B.C., the civilization of ancient Greece underwent a cultural shift which has often been referred to as the "Greek Miracle." The Golden Age which resulted from this shift is historically important because many of the Greek innovations from that time have had a powerful influence on the subsequent development of Western civilization. One of the most notable features of the Greek (or Hellenic) culture is that it was strongly concerned with the concept of humanism. The Greeks recognized that the powers of intelligence and reason made human beings unique among the creatures of the world. This pride in human affairs was reflected in such things as the treatment of deities as human-like beings and the glorification of the human body in sculpture. Related to their concern for humanism, the Greeks were also responsible for the development of the concept of the individual self. This acknowledgement of the self led in turn to the creation of democratic ideals. The height of Greek civilization was characterized by the existence of prosperous city-states, among which Athens was preeminent. It was also characterized by important achievements in science, mathematics, the arts and architecture. Among the most notable of the Greek achievements were those which occurred in the field of literature. The great literary works of this period include the historical writings of Herodotus and Thucydides, the dramas of Aeschylus, Sophocles, Euripedes and Aristophanes, and a wide variety of poetic works. In the fourth century B.C., the humanistic literature of the ancient Greeks culminated with the philosophic writings of Plato and Aristotle.

It is interesting to note that it was during the centuries immediately preceding this flowering of Greek culture that Phoenician letters were first used in the creation of a Greek alphabet. The Greek alphabet was the first effective alphabetic script in the history of humankind and many historians feel that the development of this alphabet represented an event of profound importance in the "Greek Miracle" which followed it. In this regard, Humez and Humez have claimed that "the alphabet was an invention staggering in its implication" [15]. Eric A. Havelock has likewise indicated that the Greek alphabet was "a piece of explosive technology, revolutionary in its effects on human culture, in a way not precisely shared by any other invention" [12]. The alphabet provided a simple, flexible system for storing and transmitting information, and as such it contributed to the rise of widespread literacy which occurred during the Greek Golden Age. On the basis of these arguments, this chapter will discuss the role that alphabetic literacy had in influencing Greek culture during the time.

2.2 The Dark Ages

Prior to the rise of the Greek alphabet in the eighth century B.C., the region had experienced a "Dark Age" which was characterized by an oral rather than a literate culture. This occurred despite the fact that a rudimentary system of writing had existed in Greece during the period of the Mycenaean civilization (1600-1200 B.C.). In contrast to the Greek alphabet of the Golden Age, the system of writing in Mycenaean times (known as Linear B) was extremely limited in its function and usefulness. The system was used primarily for keeping business records, and it could only be interpreted by professional scribes [2]. As a result of this situation, historians today are limited in their knowledge of the Mycenaean culture. In the words of Kenneth Dover: "There is a limit to what can be said about a past people whose thoughts and feelings we have no direct access through literature, laws or private documents" [4]. Furthermore, the Mycenaean Linear B script was syllabic rather than alphabetic, and as such it has been described as "clumsy" to use [14]. When the Mycenaean civilization disappeared in the thirteenth century B.C., the Linear B system of writing simultaneously disappeared and the following few centuries were apparently a time of non-literacy in Greece. As noted by Havelock: "No evidence is available for the use of Linear B after the fall of Mycenae, or for the introduction of the Greek alphabet at any date earlier than the last third of the eighth century B.C." [11] Thus, present-day historians know even less about this time than they do about the Mycenaean period which preceded it. Nevertheless, it can be assumed that some kind of cultural activity was taking place during these "Dark Ages." In this regard, Havelock points out that these centuries "were 'dark' only in the sense that so much about them is unknown" [12].

2.3 The Arrival of the Greek Alphabet

A revival of Greek culture began to occur in the ninth century B.C. According to Dover, "between 800 and 700 B.C., the Greek world comes to life for us in a new form" [4]. It was during that time that an alphabetic style of writing began to be used by the Greek people. The Greek alphabet was simpler and more efficient than any of the writing systems that had come before it. As such, it was superior to both the hieroglyphic style, which was based on the representation of words in the form of pictures or ideograms, and the syllabic style, which was based on "the systematic representation of syllables rather than words by signs" [21]. There is a great deal of evidence to support the claim that the Greeks adopted their alphabet from the Phoenicians, a Semitic group with whom the Greeks engaged in trade. In fact, the Greeks themselves originally referred to their alphabet as phoinikeia, which means "Phoenician objects" [21]. In adopting the Phoenician alphabet to their own use, the Greeks made some minor but significant changes. For example, the Phoenician symbols were still somewhat pictographic in that each letter represented an object (aleph stood for "ox," beth stood for "house," and so forth). In the Greek system, each letter simply represented a phonetic sound. This made the Greek alphabet more flexible in its usage than the Phoenician system. In addition, the Phoenician alphabet was designed to represent only the consonants of the language, with the vowels understood by the reader. It may be noted that this trait of leaving out the vowels is still common among the Semitic languages, such as Arabic and Hebrew. The inventors of the Greek alphabet changed this by taking the Phoenician letters that represented sounds not used in the Greek language and using them to represent vowel sounds. Thus, Phoenician letters "derived from Semitic glottal stops, and breathings, were employed to signify vowel sounds" [8]. The resultant changes produced a new alphabet which possessed many inherent advantages. For example, with only twenty-four symbols, it was a simpler writing system to learn than the earlier syllabic or hieroglyphic systems, which often contained hundreds of symbols; "it was an alphabet which was relatively easy to learn and which was well suited to the needs of the Greek language" [23]. Furthermore, since the Greek alphabet represented all of the vowels and consonants of the language, it was able to represent virtually all possible sounds of any other language as well [21]. This flexibility of language was an important factor in the flexibility of thought which characterized the Greek Golden Age.

Although it was the most concise and useful writing system of its time, researchers have noted that the Greek alphabet was not the first effort at alphabetic writing in the Western world. In fact, the earliest known attempt at alphabetic writing has been found in fragmentary inscriptions on the peninsula of Sinai. These inscriptions date from the period of the Twelfth Egyptian Dynasty (c. 1989 — c. 1776 B.C.) [5]. Oliva has also argued that earlier alphabetic systems can be found among other Semitic groups in Syria and Palestine in addition to the Phoenicians [23]. Nevertheless, the first truly successful alphabet was clearly that which was adopted from the Phoenicians by the Greeks. The exact time and place of this adoption is not known. The ancient Greeks themselves believed in a mythological tale which indicated that the alphabet was introduced to Greece by the legendary founder of Thebes, a Phoenician named Kadmos (or Cadmus) [15]. According to the historical evidence, the Phoenician alphabet probably arrived in Greece sometime during the eighth century, B.C. This is supported by inscriptions on shards of Greek pottery dating from approximately 750-700 B.C., which are the earliest alphabetic inscriptions yet to be found. Undoubtedly, the Greeks obtained the alphabet as a result of their trade activities with the Phoenicians. For this reason, the earliest examples of the Greek alphabet are found in major trading centers such as the island of Euboea and the trading-post of Al Mina on the northern coast of Syria [3]. Another piece of evidence has been found in the form of inscriptions on a goblet from a Greek colony on the island of Pithecusae off the southwestern coast of Italy [23]. The Greek alphabet evolved into a number of local variations which were based on the specific dialects of the individual city-states [10]. Nevertheless, there was enough consistency among these variations to keep the Greek language and its alphabet unified. This sense of unity was another important factor in the success of Greek culture during the fifth and fourth centuries.

The introduction of the alphabet was truly a revolutionary occurrence in the development of humankind. In this regard, it clearly marked a split between an old way of life and a new one. According to Dover, the Greek poet Homer represents a link between the old and new Greeks [4]. One of the reasons for this is the fact that Homer's great epics, the Iliad and the Odyssey, were written down at approximately the time that the alphabet was first being used in Greece. In fact, the invention of the alphabet made it possible to set down, "perhaps before it was lost forever, the heritage of the Greek heroic song" [6]. Although they represent the start of alphabetic literacy for the Greeks, the Iliad and the Odyssey also represent a summing up of the oral traditions which existed during the period known as the "Dark Ages." The historian Arnold J. Toynbee makes this point when he claims that pre-literate Greece was the source from which Homer's works "derived their themes and much of their setting as well" [25]. With the adoption of alphabetic writing, Greece entered a new era in which visual literacy took precedence over orality. The utility of the system can be seen in the fact that the Greek alphabet quickly spread its influence throughout the Western world. It was soon adopted by the Etruscans, who in turn passed it on to the Romans for use in symbolizing the Latin tongue. After that, the Greek form of the alphabet was adopted by virtually every nation of the Western world. In fact, the term "alphabet" itself stems from the first two letters of the Greek script, alpha and beta [3]. The Greek alphabet can also be seen, with variations, in the modern Slavonic languages which use Cyrillic letters.

2.4 The Success of the Greek Alphabet

The success of the alphabet in influencing the Greek Miracle was due in part to the advantages that written forms of communication and storage have over oral communication and storage. Eric A. Havelock has discussed at length the importance of "the concept of the storage of information for reuse" in this context [12]. According to Havelock, when language is encoded in written form, the cultural information contained within that language is made available for future use. As such, “human culture is not inherited but learned, and through language transmitted from generation to generation” [12]. During the Golden Age in Greece, the new alphabet was used to record many important bits of information which had never been recorded before and thus would have been lost to the passage of time. For example, lists began to be kept of important leaders and dates of important events. In addition, records of transactions and other public matters were kept. Perhaps the most important of the new written records were those which indicated the laws of the land. The most famous of these written laws were those which were formulated by Dracon of Athens in the late seventh century, B.C. The codification of laws played an important role in the development of Greek democracy. Thus, with the advent of written laws, “appeal need now be no longer to the fallible or prejudiced minds of the aristocratic guardians of the customary law, but to written codes and agreements” [14]. In other words, writing helped to insure increased fairness and justice in the administration of Greek law.

The storage of information which was made possible through alphabetic writing was also important in the development of Greece’s intellectual climate during its Golden Age. In this regard, Havelock has claimed that the “device” of the alphabet may have “furnished a necessary conceptual foundation on which to build the structures of the modern sciences and philosophies” [12]. In addition, the storage medium of writing was an important factor in the development of history as an academic discipline. Thus, alphabetic capability was the basis upon which "the accumulation of historical matter could begin" [14]. The concept of cultural storage also had an important influence on the development of humanistic thinking. In the words of Havelock, the alphabet "converted the Greek spoken tongue into an artifact, thereby separating it from the speaker and making it into a 'language,' that is, an object available for inspection, reflection, analysis" [12]. This sense of separation resulted in a new way of perceiving the self. This new perception was reflected in the development of the verb "to be," which coincided with the development of the concept of information storage. Havelock notes that the verb "to be," in contrast to the verb "to do," serves the purpose of "linking a subject and its property in a timeless connection" [13]. This reflective way of viewing the self stands in contrast to the active view of the self which existed in pre-literate times. Havelock addresses this issue by noting: "As language became separated visually from the person who uttered it, so also the person, the source of the language, came into sharper focus and the concept of selfhood was born" [13]. This new way of viewing the self had important implications for the development of Greek philosophy, as well as for the development of individualism and democratic principles.

The success of Greek culture during the Golden Age was due in large part to the fact that the phonetic alphabet was highly efficient at the task of information storage. It especially marked an improvement over oral forms of storage, in which information had to be memorized and then verbally passed on from one person to the next. With the visualized medium of the alphabet, cultural storage became more reliable than it had been in the pre-literate past. The Greek alphabet was also more effective for storage than the hieroglyphic and syllabic forms of writing, because it was both simpler and more versatile. More importantly, the Greek alphabet contributed to the achievements of the Golden Age not only because it was an efficient method for information storage but also because it could be manipulated by writers and readers alike. In this regard, "it could be rearranged, reordered, and rethought to produce forms of statements and types of discourse not previously available because not easily memorizable" [12]. This factor opened the way to increased creativity in both context and style. In other words, the manipulability of the alphabet enabled writers to be more creative in their use of language. In addition, this new feature of written language opened the way to a unique form of interaction between the writer and the reader, with the latter often acting as an interpreter as well as an observer. In his book, The Muse Learns to Write, Havelock points out that alphabetic writing allowed for a novel use of language "in which a reader scanning as he read could recognize at leisure and 'take in' and 'think over'...He could also respond with a commentary of his own which might be novel" [13] Therefore, with the Greek alphabetic revolution, writing was no longer used merely for religious and commercial purposes. As noted by Oliva, with the Greeks, "the alphabet was not used merely for day-to-day trade, but very soon served a literary purpose as well"

[23]. This creative use of language was an important factor in the triumphs of the Greek Golden Age. Furthermore, inventive writing played an important role in the development of the art of Western literature.

The alphabet was related to the success of Greek culture in another way as well. Specifically, it contributed to the development of a literate society during the nation's Golden Age. In fact, Murray has referred to ancient Greece as "the first literate society" [21]. Evidence of widespread literacy in Greece can be traced back to the late eighth century B.C. In the Greek city-states, "writing was in such common use by 700 that people scribbled on potsherds" [10]. By the fifth century, literacy had become even more widespread among the Greek people. Evidence of this can be seen in the practice of ostracism which was utilized in the city-state of Athens. This practice permitted voters to write down the names of politicians that they wanted removed from office. If enough votes were received, the named politician would not only be removed from office but would be banished from the land. The relationship of literacy to this practice can be seen in the fact that the existence of ostracism "presupposes large numbers of citizens able to write at least the name of a political opponent" [21]. The reason literacy became popular in Greece at that time was because the alphabet adopted from the Phoenicians was simpler to use and easier to learn than any other writing system that had come before. For example, the Akkadian script of the second millennium B.C. had 285 signs; the Linear B system of Mycenae had 88 signs; and the the Cypriot system of Cyprus contained 56 signs [8]. With only twenty-four letters, the Greek alphabet "could be learned, and was, by almost everyone" [9].

2.5 The Transition to Literacy

The transition to literacy did not take place overnight. In fact, it took nearly four centuries for the shift from orality to popular literacy to take place: from the first appearance of alphabetic inscriptions in the eighth century B.C., to the peak of Greek civilization around the beginning of the fourth century [12]. By the time of the Greek Golden Age, however, the idea of literacy had become extremely important to the free citizenry of Greece. In this regard, the ability to speak and read Greek was considered a matter of national pride. Conversely, those who were not able to make use of the Greek language were designated by its speakers as being "barbarians" [1].

It is clear that literacy provided many benefits to the Greeks of the Golden Age. In the realm of social evolution, these benefits included the development of increased political freedom. In the words of Peter Green, the Greek alphabet "was one of the great democratizing forces of ancient culture" [9]. In the age of orality, despotic kings were often able to hold sway over the people. This was because there were no adequate means for storing, and thus accurately remembering and using, the laws pertaining to limits on government power. This changed with the rise of alphabetic literacy, when the people at last had the means for increased control over both political affairs and their own lives. According to Oswyn Murray, language in pre-literate times was “fluid” in its descriptions; by contrast, literacy enabled people to “fix” words and their meanings. This had a powerful impact on the development of Greek cultural history. Thus: “The evasions and reinterpretations of the oral tradition ceased, and the resulting gap between written statement and actual experience led to the formation of a critical approach to life based on a notion of the essential rationality of all aspects of reality, public and private” [21]. This new way of perceiving life resulted in an increased emphasis on the values associated with individualism. As such, the revolution of the alphabet can be seen as contributing in part to the rise of democratic viewpoints in ancient Greece.

Another benefit of a literate society over a non-literate society can be seen in the way that writing affects thinking. According to Havelock, the adoption of an effective system of writing results in numerous “conceptual advances” for the society making the change [13]. Havelock also claims that the way humans use their senses and the way they think are interconnected. Because of this, “in the transition from Greek orality to Greek literacy the terms of this connection were altered, with the result that thought patterns were altered also” [13]. By adopting an alphabet with greater flexibility, the Greeks' manner of thinking also became more flexible than ever before. This new way of thinking can be seen in the cultural achievements of the great writers and artists of the Greek Golden

Age.

2.6 The Literate Population Reaches a Critical Point

An important element which led to the Greek Miracle was the fact that literacy had become possible for a larger segment of the population than ever before in the past. In earlier societies, the craft of writing was restricted to the fields of commerce and religion. In addition, the interpretation of written symbols was restricted to an elite group of professional scribes. Havelock calls this state of affairs a "craft literacy," in contrast to a true, popular literacy, such as that which existed in the Golden Age of ancient Greece. Widespread cultural accomplishment is not possible in this type of non-literary society, in which the "secrets" of writing are "carefully nurtured by its practitioners" [12]. However, by the fifth century B.C., the "select masses" of Greece had attained a high level of literacy. The term "select masses" was not a contradiction for that period, because the class system of the time defined many people — such as slaves, women, and certain social classes — as being excluded from the right to public representation. Furthermore, although democracy was the ideal of the Greek city-states, the ruling classes continued to be the wealthy and the aristocratic. The well-to-do families of ancient Greece referred to themselves as the <u>aristoi</u>, or "best people" [2]. Their existence was sharply contrasted by that of the farmers and other common people of the society. In the words of Burns, "the very idea that such people might have political rights still lay in the future" [2]. Nevertheless, the fifth century B.C. saw a rise in literacy among those members of Greek society who were considered worthy of education and political representation. When this level of literacy attained a certain point, the conditions were established which enabled the cultural Greek Miracle to occur.

Literacy became possible for this large segment of the Greek population because the recently acquired alphabet was simple to learn and easy to use. In addition, the resources for learning the alphabet were widely distributed, and the system of writing became well understood throughout the society. Furthermore, the Greek educational system of the time played an important role in the spread of literacy. By the time of the Golden Age, Greek education was highly developed and accessible to all free members of the society. By contrast, there is no evidence of any effective educational system during the pre-literate period of Greek history. This was true even when a system of writing was used, as in the ancient Mycenaean culture. True literacy did not exist during that period, because the only people capable of interpreting the written symbols were scribes and other professionals [20]. Havelock argues that the education of the Greek upper classes did not focus on alphabetic writing until late in the fifth century B.C. Although oral forms of education, such as memorizing works of poetry, were used extensively during the early period of the Greek Golden Age, "organized instruction in reading at the primary level, that is, before the age of ten, cannot have been introduced into the Athenian schools much earlier than 430 B.C." [12]. Murray, on the other hand, claims that education in reading and writing was becoming widespread in Greece at a somewhat earlier date. The earliest evidence for this type of education appears at about the year 500 B.C. Thus, a report by the historian Herodotus indicated that a disaster occurred in the town of Chios in 496, "when the roof fell in on a school 'where children were learning their letters'"[21]. At any rate, once it became established, literacy education soon became a standard practice throughout the Greek world. At first, the only members of society to receive this type of education were those of the aristocratic class. However, the schools (or gymnasia) were "gradually opened to other social classes among the citizenry, in line with the evolution of society towards a 'democratic' levelling" [20]. Even with this development, women continued to be deprived of educational opportunities.

The education of children proved to be a vital element in terms of the spread of literacy in ancient Greece. The simplicity of the Greek alphabet played an important role in this process. Thus, in contrast to the systems of "craft literacy" in the past: "The Greek system by its superior analysis of sound placed the skill of reading theoretically within the reach of children at the stage where they are still learning the sounds of their oral vocabulary. If acquired in childhood, the skill was convertible into an automatic reflex and thus distributable over a majority of a given population provided it was applied to the spoken vernacular" [12]. Therefore, the literary revolution in ancient Greece was due in large part to the training of the young people of the nation, which was in turn due to the institutionalization of that training at the elementary level [12]. Even during the literacy period, the structure of Greek education focused largely on rhetoric and the other arts of oration. Emphasis was also placed on such elements as physical training and education in music and the arts. In terms of reading and writing, a great deal of emphasis was placed on studying the literature of Homer and the others. In this regard, it has been noted that "the alphabet came just in time to write down the Illiad and the Odyssey ascribed to Homer, which became the principal educative influence upon all Greeks for ever more" [7]. By the time of the Greek Golden Age, education was clearly perceived as having great value in the development of culture. In fact, "the high value attributed to this education is evidenced by the fact that the severist punishment imposed on recalcitrant subjects was to forbid them to educate their children" [1]. It is apparent that the educational system in Greece played a part in the development of democratic ideals during that time. As such, the high quality of Greek education was responsible to a large degree for the rise of the Golden Age. In addition, after the Greek educational system was adopted by the Romans, its influence became absorbed into the history of western civilization as a whole [20].

2.7 Why No Egyptian or Phoenician Miracle?

The preceding arguments indicate that literacy skills were among the main reasons for the rise of the Greek Miracle. On this basis, the question may be raised regarding why a similar "miracle" did not occur in earlier societies that also had a form of writing. For example, neither the Egyptian nor Phoenician societies attained the cultural heights that the Greeks did. The answer to this question is that the Greek writing system was superior to those of the earlier civilizations. In particular, the Greek system of writing had the advantage of being alphabetic and hence being more useful for the storage and retrieval of information. In addition, the Greek alphabet was a standardized writing system which was relatively easy to learn. This factor contributed to the rise of widespread literacy in ancient Greece, a condition which never caught hold in the previous societies.

The Greek writing system was especially an improvement over the oral systems which existed in pre-literate times. In terms of cultural development, a number of factors limit oral systems. For example, in order to transmit oral information from one generation to the next, stories and other texts had to be memorized. This memorization was aided by utilizing rhythm as a poetic device. In the words of Havelock, "under conditions of non-literacy in Greece, and of craft literacy in pre-Greek cultures, the conditions for preservation were mnemonic, and this involved the use of verbal and musical rhythm, for any statement that was to be remembered and repeated" [12]. Although it was useful as an aid to memory, this use of rhythm had the effect of drastically constraining what words could express. Thus, prior to the advent of literacy in Greece, rhythms had "placed severe limitations upon the verbal arrangement of what might be said, or thought" [12]. This changed with the adoption of the Greek alphabet, which provided a visual method of storage in place of memorization. Havelock points out the importance of this improvement by stating that "the alphabet, making available a visualized record which was complete, in place of an acoustic one, abolished the need for memorization and hence for rhythm" [12]. The oral systems of language were also limited in their usefulness by the fact that memorization was aided by the use of simple, archetypal themes. Thus, in order to insure memorization, the concepts of the oral societies were limited in their degree of complexity. Because of this factor, the myths and legends of the pre-literate period tended to "deal with action and thought in typical situations and use a style which is formulaic and repetitive" [12]. By contrast, the Greek alphabetic system introduced a new and vastly improved method for information storage and retrieval. This new method did not rely on memorization and thus it was able to overcome the limitations which are inherent in the use of rhythms and archetypes in shaping thought. According to Havelock: "The warehouse of storage, no longer acoustic but visibly material, was extendible, and also the documented contents need no longer relate only what was already familiar and so easy of recollection" [13]. This was a positive change in the evolution of humankind because it opened new avenues for the expression of ideas. In turn, this development contributed to the rise of the Greek literate culture which was unique throughout the ancient world.

The Greek alphabetic writing system was also a clear improvement over the pictographic styles of writing which had existed in earlier cultures. One of the most notable of these systems can be found in the hieroglyphs which were used to adorn stone walls and other surfaces in ancient Egypt. As in the case of pure orality, hieroglyphic writing was extremely limited in terms of conceptual complexity. Thus, one of the major problems with pictographic writing was the fact that there are "plenty of things to talk about that don't readily lend themselves to pictographic representation" [15]. Such writing is able to describe people, places and things; however, it is very inadequate in terms of expressing higher levels of intellectual thought. Another problem with hieroglyphic writing is the fact that it was not as standardized as the Greek alphabet. This resulted in a great deal of difficulty in interpreting the pictorial figures. In the words of Humez and Humez: "The vast majority of the consensual signs of early Near Eastern orthography took on a wholly arbitrary, nonrepresentational cast, becoming utterly indecipherable to all but the professional initiates to the art of writing" [15]. This difficulty in reading hieroglyphics resulted in the "craft literacy" which excluded the average citizen from the skills of reading and writing. Because of this, Egypt and the other ancient cultures utilizing pictographic writing were incapable of reaching the heights of cultural development which were attained by the Greeks.

2.8 The Superiority of the Greek Alphabetic Writing System

The Greek system of alphabetic writing was superior to previous systems which were based on the use of syllabaries. The phonetic alphabet was more concise and flexible than the syllable systems, and as such it provided an improved method for storing and manipulating cultural information. Because the Greek alphabet was both accurate and simple to use, "its invention brought the art of writing within everybody's reach — in contrast to the effect of the earlier invention of the Sumerian, Egyptian, and Chinese scripts, which were so complex and clumsy ... that they were bound to be the monopoly of a handful of privileged specialists" [25]. Again, as in the case of hieroglyphics, the syllabic systems resulted in the dominance of the "craft literacy" in which a professional class of scribes were required in order to read and interpret writing [21]. Because syllabic writing was an elite concern and was denied to the common citizenry, the pre-alphabetic cultures which depended upon this type of writing were unable to attain the cultural achievements of the Greeks. The syllabic scripts were also limited in their usefulness because, like the pictorial scripts, they were of necessity reduced to dealing with simple concepts. In order to be sure that readers would be able to understand their texts, the writers of syllabic scripts resorted to the use of archetypes and standardized versions of human behavior which could be "read easily and correctly" [12]. The result of this situation was similar to that which occurred in the hieroglyphic societies. Thus, there was a lack of common literacy among the syllabic societies which likewise resulted in a lack of intellectual and cultural development. In contrast to the limitations inherent in syllabic scripts, the great works of Greek literature were far more flexible in their style and far richer in their content. As such, the writings of the Greeks provide "a larger dimension of human experience, so much more diverse, personal, critical, subtle, humorous, passionate, ironic, and reflective" [12]. This greater depth of expression was a vital factor in the development of the "Greek Miracle" of the fifth and fourth centuries B.C. Furthermore, it is evident that this enhanced writing ability was due to the versatility, conciseness, and other advantages of the Greek alphabet.

The Mycenaean civilization which preceded the Greek Golden Age by several centuries never attained great cultural heights despite the existence of an elite system of writing. This was because the Mycenaean system of writing was clumsy and difficult to learn. It was adequate for keeping business and religious records, but it was not sufficient for the expression of complex ideas which are inherent in true literary writing. A similar problem existed in the other pre-Greek societies such as Sumer and ancient Egypt. The combined simplicity and flexibility of the Greek alphabet changed all this, however, because it "meant that far more people could read and write in the Greek world than in Egypt or Mesopotamia, which used writing-systems of subtle beauty but horrible complexity" [4]. Because of the adaptations made in the eighth century B.C., the Greek alphabet was even superior to the Phoenician script from which it was directly borrowed. The major disadvantages of the Phoenician alphabet, as well as many other Semitic scripts, is seen in the fact that it failed to indicate the vowel sounds of the language. This made the system more simple because it reduced the number of signs required for designating the letters of the alphabet. By indicating only the consonantal sounds, the Phoenician alphabet was certainly easier to use than previous scripts which sometimes contained hundreds of symbols for this purpose. However, this practice also resulted in a writing system which was "considerably more ambiguous than syllabic scripts" [21]. Toynbee explains this by noting that the Phoenician gain in conciseness "was offset by a loss of precision, since there will be a number of alternative ways of supplying vowels for a word written in consonantal letters only" [25]. The Greeks made vast improvements in this system by simply adding a few vowels. This simple change enabled the alphabet to represent all of the phonetic sounds of the Greek language. As such, "the consequent trifling loss in conciseness was out-balanced by an immense gain in both precision and clarity" [25].

2.9 The Greek Miracle and Its Impact

It is clear that the Greek Miracle occurred in Greece and not in some other ancient civilization because of the practicality and usefulness of the alphabet. There were three major ways in which the Greek alphabet marked a notable improvement over previous writing systems: (1) it was superior in terms of storing and transmitting information; (2) it was simpler and more flexible and thus encouraged the rise of widespread literacy; and (3) it encouraged new, creative modes of thinking as well as writing. In terms of information storage, the Greek alphabet was obviously a great improvement over oral systems which were based on memorization and the idea of verbally passing information on from one person to another. This improvement was related to the fact that alphabetic writing added a visual aspect to language. This visual aspect enabled the writer to be separated from the words themselves and in turn made the language easier to perceive and use. In contrast to oral systems, a statement in the alphabetic system did not need to be memorized in order to be recalled at a later date. Rather, "it could lie around as an artifact, to be read when needed; no penalty for forgetting – that is, so far as preservation was concerned" [12].

The Greek alphabet also contributed to the rise of the Golden Age by encouraging the spread of literacy. This increased literacy was due to the fact that the Greek alphabet was easier to learn and was more accessible than previous writing systems. The earlier pictorial systems were especially complex because they required the use of separate symbols to represent each individual word. However, the syllabic systems were also extremely complex because languages generally contain many more syllable combinations than phonetic sounds. By focusing on the representation of phonetic sounds, the Greeks were able to arrive at a new and simpler approach to alphabetic writing. In addition to being more flexible, the Greek system was more functional because its twenty-four characters were capable of representing virtually all of the possible sounds of the language [15]. The simplicity and adaptability of the Greek alphabet made it relatively easy to learn and use. As a result, there was a vast increase in literacy during the period which led up to the Golden Age of Greece. Clearly, there are numerous benefits to be found in a literate society over an illiterate one. In particular, increased literacy enabled the Greek culture to become more intellectual and humanistic than any other culture that preceded it. This new intellectual climate resulted in the great accomplishments of the Golden Age, many of which continue to influence the Western world in the present day.

The Greek alphabet also inspired great innovations in writing because its flexibility enabled the expression of complex thoughts, as well as creative ways of thinking. Havelock has pointed out that oral societies were especially limited in this regard. This is because a great deal of "brain power" is used up in the process of memorizing large blocks of information [12]. With the improved storage system of the Greek alphabet, the human mind was at last liberated to do more creative thinking rather than mere memorizing. In addition, by making the language visual rather than simply oral, the alphabet played an important role in the development of a sense of "novelty" in writing. According to Havelock: "The acoustic medium, being incapable of visualization, did not achieve recognition as a phenomenon wholly separable from the person who used it. But in the alphabetized document the medium became objectified" [13]. This objectification meant that language could be used as a tool for making important clever statements. This capability led to the rapid development of intellectualism and creative literary thought in Greece. Thus, the novelty inherent in alphabetic writing was a vital factor in the spread of literacy and the enjoyment which comes from the ability to read. The visual medium of the alphabet was also an important factor in the further spread of literacy throughout the ancient Western World. As such, "the alphabet, by encouraging the production of unfamiliar statement, stimulated the thinking of novel thought, which could lie around in inscribed from, to be recognized, be read and re-read, and so spread its influence among readers" [12].

The Greek alphabet was clearly a revolutionary development in the history of humankind. It ushered in an era of literacy and a new way of thinking which has come to characterize the way of life in the Western world. Ironically, literacy underwent a decline between the fall of the Roman Empire and the invention of the printing press in the fifteenth century, A.D. During that time, "most of Europe reverted to what in effect was a period of craft literacy employed by clerics" [12]. Nevertheless, prior to that decline, the alphabet had played an important role in enabling the cultural innovations of the Greek Golden Age. The existence of a simplified form of alphabet is important in explaining why this miracle occurred in Greece and not in any other ancient civilization. In addition to encouraging increased literacy, the visuality of the alphabetic medium paved the way toward advancements in science and philosophy as well as literature. Therefore, "it is no accident that pre-alphabetic cultures of the world were also in a large sense the pre-scientific cultures, pre-philosophical and pre-literary" [12].

The development of the Greek alphabet enabled the writer of an idea to have a sense of separation from the written thought. Ideas no longer needed to be remembered in order to be expressed, and as such could be altered or expanded upon at a later date. This allowed for greater objectivity in thought than had ever occurred before. Furthermore, this separation between the idea and the mind helped to give rise to the concept of individualism, which profoundly influenced the development of Western culture and thought even to the present day.

Chapter 3

The Structure of the Simulation

3.1 Introduction

Before beginning a simulation of literacy, it is important to set up a simulation of a non-literate or "oral" community first as a standard that can be used to compare against one in a literate environment. Investigating all the factors at work in an illiterate environment first allows us to really set a strong framework for our study of an environment where reading and writing are found.

We want to keep our initial setup as simple as possible. This will help us better ensure everything is running smoothly and provide a nice base to which we can add more interesting and complex features.

This chapter will describe our simulation of an oral community: the parameters involved, and the actual simulation.

3.2 The Setup

3.2.1 Simorgs

Each of our simulated organisms is referred to as a *simorg*. The simorgs will occupy a fixed location and will not move throughout the simulation. The genetic makeup of each of our simorgs is identical. Each simorg can hear, think, and speak. This literally translates to a simorg with an input buffer for "hearing," a short term memory for "thinking," and an output buffer for "speaking." The input and output buffers of the simorg represent the external state of the simorg. This can be considered the "body" of the simorg since the simorg hears and speaks via these buffers. Oral communication is achieved by way of the external state. The number of external state variables is a parameter we will want to modify when considering a literate community. Throughout the oral communication simulation simorgs will have just the two external state variables — the one for hearing and the one for writing. A bit string found inside the simorg can be considered its internal state, that is, what it is thinking at the moment. The internal state is not perceived by any other simorg and is the only internal state of the simorg.

3.2.2 Behavior

Each simorg is a finite state machine since its behavior will be determined solely by a *transition table*. Further, its entries do not change throughout. All simorgs will follow the same transition table. This table will take into account the current state of a simorg together with the states of its immediate neighbors.

The inputs and outputs for this transition table are determined at random at the beginning of our simulation. To maintain a deterministic system, it is important that all randomization involved occur before the simulation actually begins. Although a nonderministic system is certainly more realistic, a deterministic finite state automation (DFSA) must cycle. We can easily determine the length of this cycle and use it as factor of comparison between our illiterate and literate environments. In addition, according to Langton "once the local physics and initial state of a DFSA have been chosen, its evolution is uniquely determined" [16].

The transition table for our illiterate environment will consist of two input entries and two output entries. The two input entries correspond to what the simorg is currently hearing as well as thinking. The two output entries correspond to what the simorg is speaking and what it will be thinking later. So, we can essentially think of our transition table as a function which will determine for us a new state based on our current state. That is,

$$F(S) = S'$$

where S represents the input state of the simorg and S' the output state. This is known as a *transition function*. This transition function uses what the simorg is currently hearing and thinking to determine what exactly the simorg will say and think next in response.

This approach for modeling artificial life is known as the *cellular automata* model. A cellular automata model is one in which "an array of cells may change through (discrete) time according to well-defined rules" [24]. The number of entries or "rows" in this transition table is a parameter decided upon by the user before the simulation commences. Another parameter set at the beginning is the number of simulated organisms that will be present during the simulation.

3.2.3 The Quiescent State

An important parameter, on which much attention of the simulation will be focused, is known as the λ *parameter*. The impact of λ was first noted by Chris Langton in his work on computation and we'll define it in a similar fashion to Langton. First, let's choose a state s_q and call it the *quiescent state*. We'll choose this s_q to be the output pair $(0, 0)$. Let there be n transitions to this state s_q using the transition function. The remaining $K_N - n$ transitions will be filled with random values. Then, as Langton defined,

$$\lambda = \frac{K_N - n}{K_N}$$

If $n = K_N$, then all the transitions in our table will be to the quiescent state and $\lambda = 0.0$. If $n = 0$, then there will be no transitions to $(0, 0)$ and $\lambda = 1.0$ [16]. A good way of thinking of the lambda parameter is the probability that a simorg will enter a non-quiescent state.

If a simorg has gone to the quiescent state, both of the simorg's external states are 0 at the end of a time unit, indicating that it is neither speaking nor thinking anything. If a majority of the simorgs in the community have gone to this state and are interconnected, the entire community will soon begin neither hearing, thinking, nor speaking anything (*sleeping*). Hence, the λ parameter will be a very powerful parameter in influencing the behavior of a simorg as well as the entire community.

In Langton's research, the λ parameter varied from 0.0 to 1.0 in discrete steps using randomly constructed transition functions. He closely examined the dynamics of the system during discrete steps and found behavior first starting out as periodic or repetitive and eventually turning complex as the λ parameter was increased. Most interestingly, he found a small region he termed the "transition regime" of "complicated structure" between the periodic and chaotic behavior [17].

In a later chapter, we will attempt to find this "transition regime" in our system and study the effects of the λ parameter on the dynamics of the community as it varies. First, we present the makeup of our entire system.

3.2.4 The Simorg's Community

Each of our simorgs may or may not have "neighbors." The probability that one simorg will be connected to another is called the *interconnect probability.* The interconnect probability will be a parameter we can modify as we wish to vary the number of neighbors a given simorg will have. A very high interconnect probability would indicate that a simorg will be connected to a majority of the other simorgs in the community. A very low interconnect probability means just the opposite. This interconnect probability, like all other parameters, is determined by the user at the onset of the simulation and not modified during the run.

To determine the number and name of a simorg's neighbors, we use an *interconnect matrix.* Each simorg represents a "row" or vector within our interconnect matrix. Within each vector, we find a slot for each of the simorg's neighbors. The interconnect probability will determine at the onset if this slot will be marked. If marked, it indicates a connection between the simorg of the given row and a neighboring simorg. A simorg is never connected to itself.

3.3 The Simulation

At the onset of the simulation, what each simorg is hearing and thinking will be determined at random. Once this is done, our community has been built and populated, listening to its environment, and thinking about a particular "concept".

We can commence the simulation.

Starting with one simorg and continuing in round-robin fashion with all the other simorgs in the community, each simorg will act or respond to its current stimuli based on prescribed rules of behavior in the transition table.

A simorg will begin thinking a new idea so long as both the internal and external state have not gone to the quiescent state or, by chance, the current state maps into an output that is identical to its current one. A simorg will also speak, that is, data will be transferred to a simorg's output buffer based on the current state. The simorg, however, will only be heard by those it is connected to. So, the simorgs it is connected to receive a copy of what it is speaking at this point.

After all simorgs have had a chance to act, we perform a *checksum* of all the simorgs' internal and external states. These values, along with the current time step, are stored and analyzed to see if the entire community of simorgs has returned to a state in which they all were hearing, thinking, and speaking the exact thing after the entire community has been given a chance to act. In such a situation, a *cycle* has been reached. If no cycle is detected, the community has "aged" by one time unit and the simulation returns to the first simorg to act based on its new current state. It should be noted that a duplicate checksum is not a full proof guarantee that a cycle has been reached since that sum could have been generated by different sequence of states. In order to increase our chances this has not occurred, the checksums of each individual simorg at the current time unit are compared with those where the identical community checksum has been found.

When a cycle is reached, the simulation is stopped. The length of the cycle and the time it took the community to reach a cycle (known as the *transient length* or *tail* of the system) are calculated. If the system has gone to the quiescent state, it will have a cycle of one since we set up our model so that once a simorg is neither hearing nor thinking anything, it will continue to do so.

3.4 The Parameters

Table 3.1 provides a summary of the five parameters N, T, S, P, and λ we will be using in our simulation. The user determines the values for all the parameters at the start of the simulations. One additional parameter that we will be using is a random number seed that allows us to start off a new sequence of pseudo-random numbers. The values are chosen at the onset of the simulation and never modified during the run.

3.5 A Sample Oral Community

Let's take a look at a simple example of our simulated community. As you see in Figure 3.1 , we will start with a community of three simorgs ($N = 3$). The

Table 3.1: A summary of the parameters at work in our simulation

N = Number of Simorgs
T = Number of Transition Table Entries
P = Interconnect Probability
λ = Lambda Parameter
S = Random Number Seed

bit string inside the circle represents what the simorg is currently thinking. We can think of this as the brain of the simorg. The rectangles above and below the brain are the ears and mouth of the simorg so to speak. These are the input and output buffers of the simorg representing what the simorg is currently hearing and speaking.

The initial values each simorg is hearing and thinking are simply random bit strings of a specified length in the program. In this example, we will use a string value no larger than the decimal number 4.

This tells us we will have a transition table consisting of 16 different entries corresponding to all the possibilities that the simorg may be hearing or thinking and the actions it should take in response. The outputs or resulting behavior of each of these different inputs are all randomized with a starting seed of 196. We will be using a λ parameter of 0.8 in this example. This tells us that we'll have three input entries which go to the quiescent state (20% of 16 entries = $3.2 \approx 3$). The input pair (0,0) will, by definition, go the quiescent state. We then go in and literally zero-out the outputs of two other random entries.

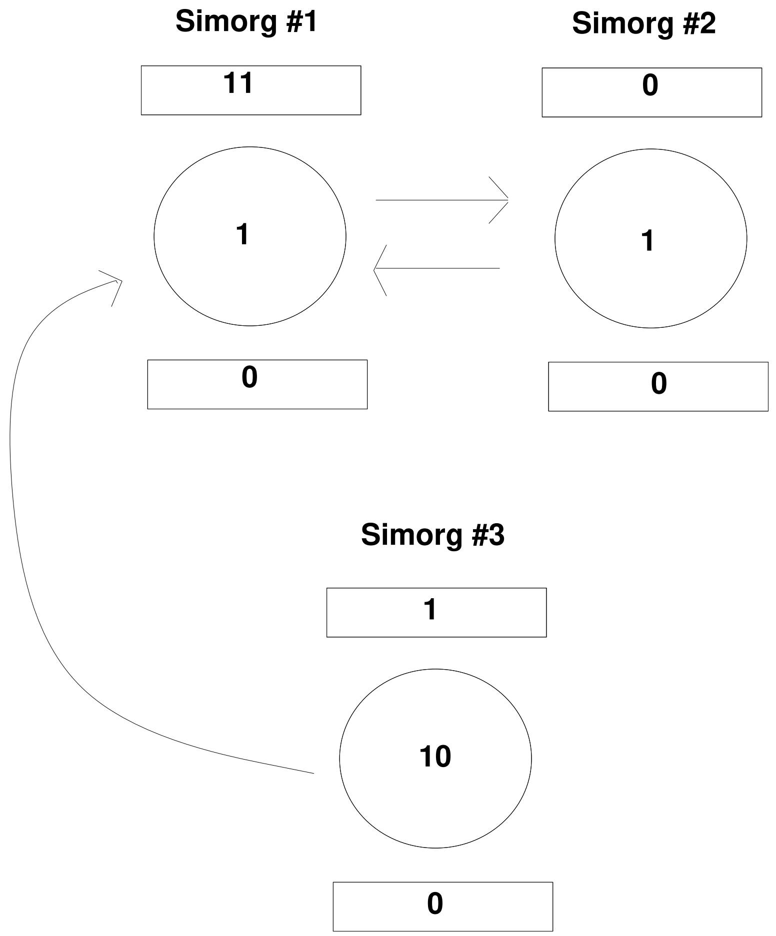

Figure 3.1: Our oral community after the initial setup before running commences

Table 3.2: The transition table for our example run of a three simorg oral community where our information strings are no larger than decimal 4. So, we have sixteen different possibilities for behavior we must program into the simorg's genes.

Input		Output	
Hearing	Current Thought	Speaking	New Thought
0	0	0	0
0	1	11	0
0	10	10	1
0	11	10	0
1	0	10	11
1	1	0	11
1	10	0	0
1	11	0	0
10	0	11	1
10	1	10	11
10	10	0	1
10	11	1	0
11	0	1	1
11	1	0	1
11	10	0	10
11	11	10	11

The interconnect probability for this example is set at 0.5 and the resulting interconnect matrix is shown in Table 3.3. A summary of all our parameter values for this example simulation are found in Table 3.4.

Table 3.3: Interconnect matrix for a three simorg community with $P = 0.5$ and $S = 196$

	Neighbors		
Simorg #	1	2	3
1		X	
2	X		
3	X		

Table 3.4: Parameter values for our sample simulation of a three simorg oral community

Parameter	Value
N	3
T	16
S	196
P	0.5
λ	0.8

Once the community is all set up and randomly initialized, simorg #1 is hearing the bit string 11 and thinking 1 as we saw in Figure 3.1. Using its built in rules which determine how it will react to this stimulus in the transition table, Simorg #1 continues speaking and hearing the same information (a 11 and 1 respectively). Simorg #2, however begins thinking a new thought of 0 and starts speaking a 11. This 11 is heard by Simorg #1 since it is a connected to Simorg #2, a neighbor. Simorg #3, by the transition table, begins thinking and speaking nothing now. The boredom of Simorg #3 is noticed by Simorg #1 and a 0 is now in its input buffer since a connection exists between these two simorgs. This ends the first cycle and the contents of each simorg at this point are summarized in Figure 3.2.

This process continues for three additional time units as we see in Figures 3.3 through 3.6. At the end of each time unit, a checksum of the community is performed and we verify that this snapshot of the community has not existed before. After the fifth time unit, the state of the system is identical to the way it was following the third time unit and the system comes to a stop after the fifth time unit. In this example, we end up with a cycle length and transient length of 2 time units.

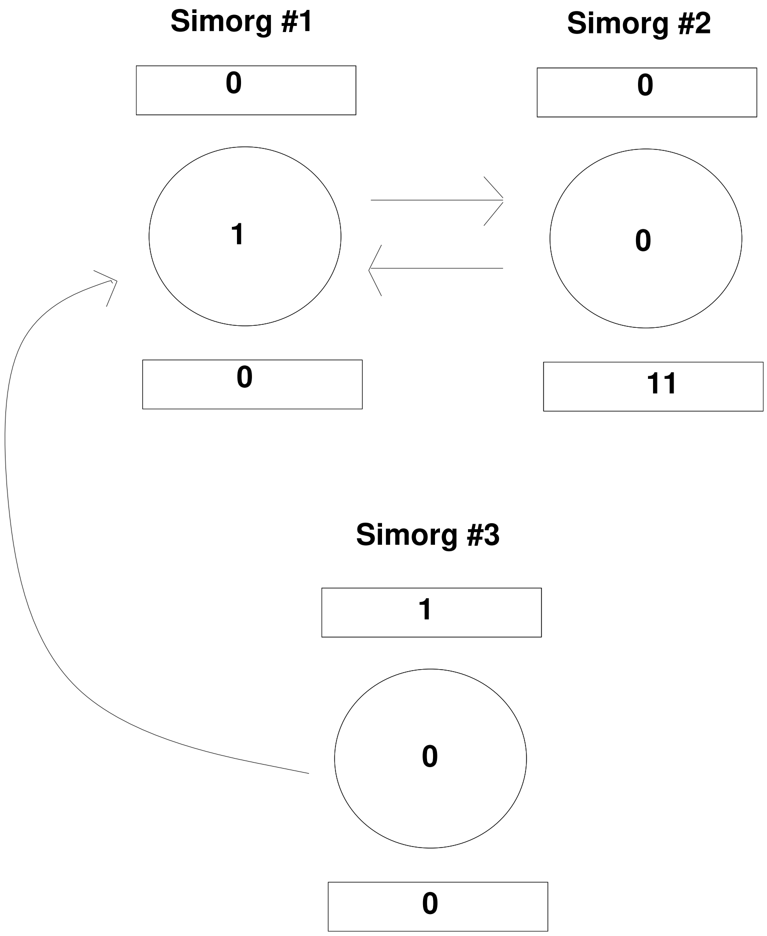

Figure 3.2: The oral community after one time unit

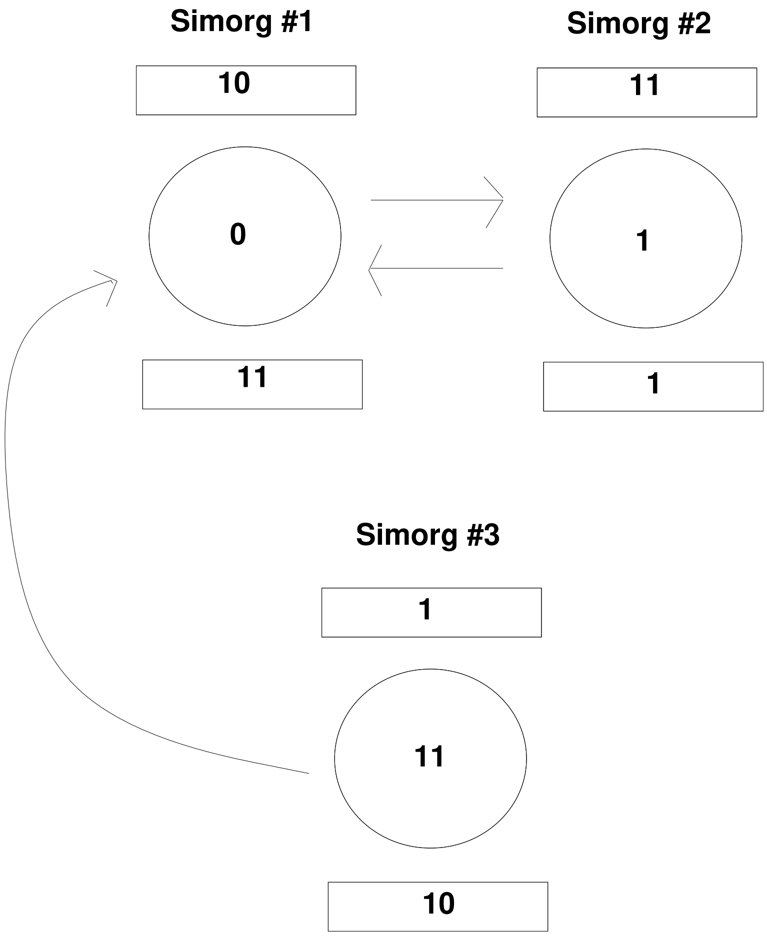

Figure 3.3: The oral community after two time units

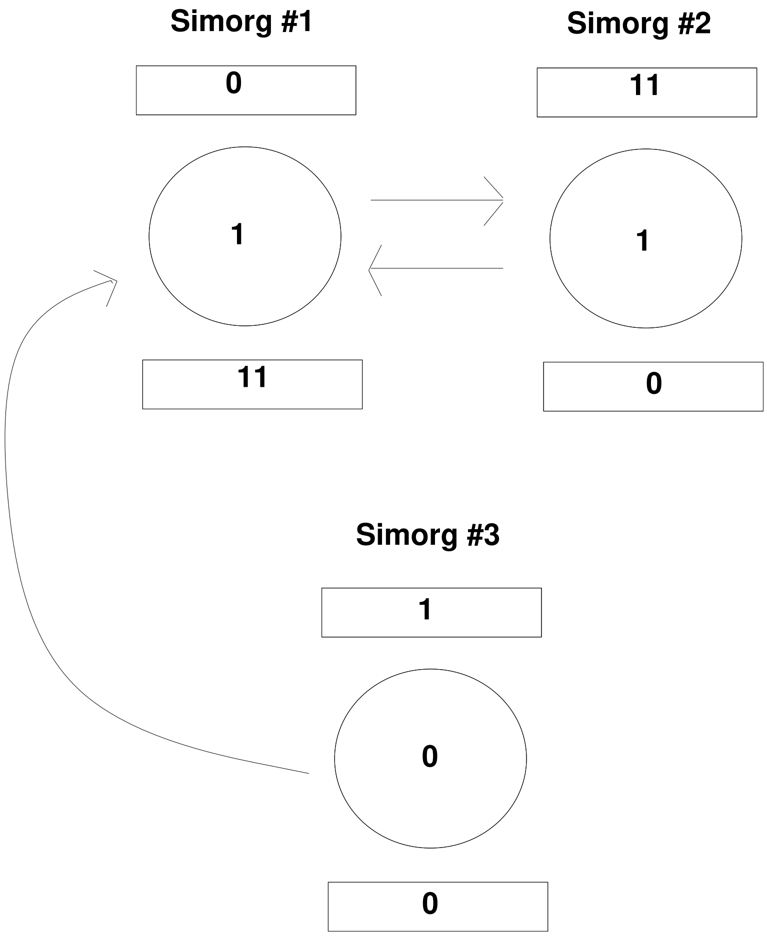

Figure 3.4: The oral community after three time units

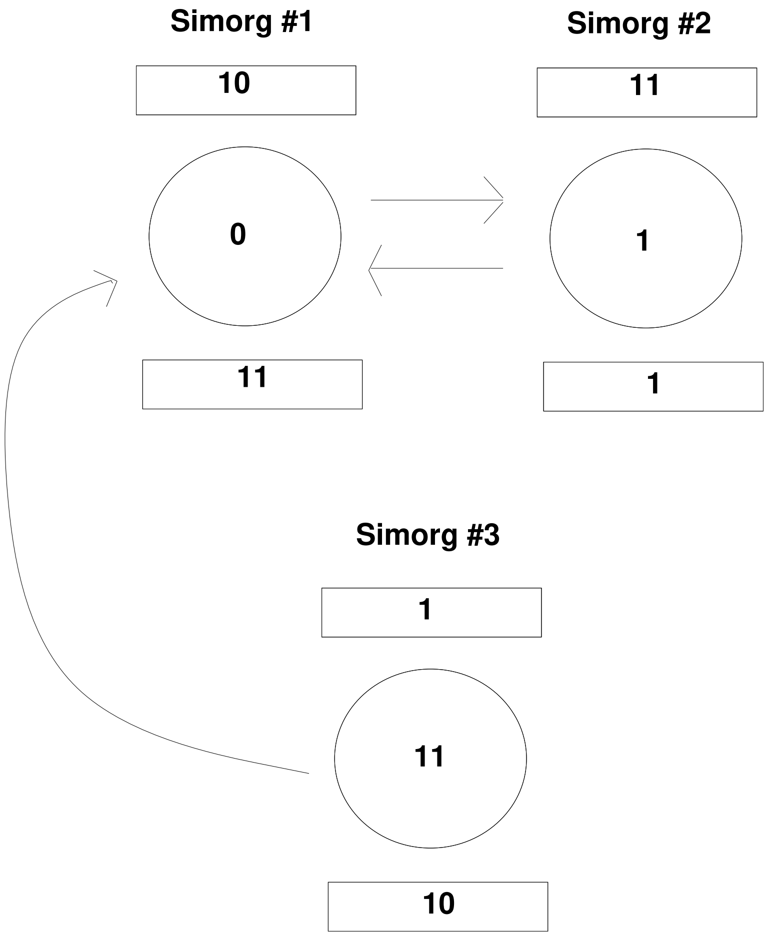

Figure 3.5: The oral community after four time units

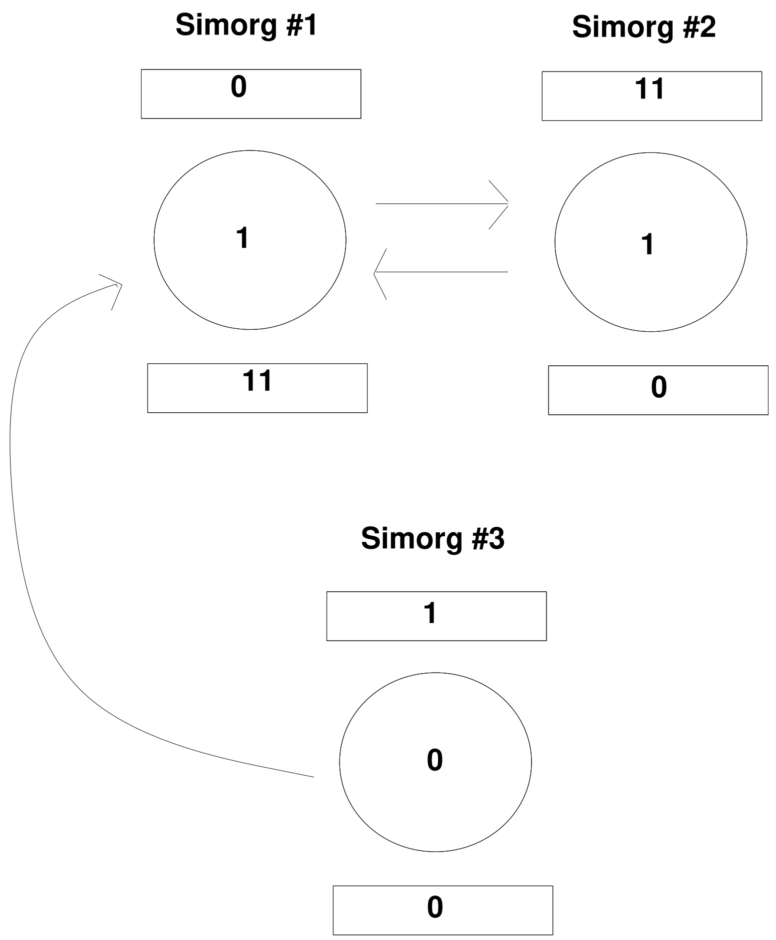

Figure 3.6: The oral community after five time units. The simulation comes to a stop at this point since we have returned to the same stage as we were in after two time units. So, we have a cycle length of two and transient length of two in this example.

Chapter 4

The Dynamics Of Oral Communication Under Different Parameters

4.1 Introduction

This chapter will detail the results we found in our simulations of an oral community. We'll investigate the effects variations in the number of transition table entries, number of simorgs, the interconnect probability, and the lambda parameter had on the dynamics of the systems. The most interesting results were found as we varied the lambda parameter and we'll look at this in detail as the lambda parameters varies over the interval $[0.0, 1.0]$.

We'll be using the same notations for our parameters as we did in the last chapter — N, T, P, λ, and S to represent the number of simorgs, number of transition table entries, interconnect probability, lambda parameter, and random number seed respectively.

4.2 Random Number Seed (S)

The random number seed allows us to start off a new sequence of pseudo-random numbers. It is a positive integer that is chosen by the user at the start of a simulation. By varying the random seed, we can start off the simulation of our community each time with a different set of internal states at the onset and a different set of behavior possibilities for these internal states. One nice advantage of using a random number seed which is chosen by the user is that if we found an interesting set of results occurring with a particular seed value, we could re-run the simulation and analyze these results even further with some different parameters or features using the same seed value. It would not be practical to re-run a simulation under the same conditions if we had used a random seed generated by the internal clock of a computer system. I usually ran most of my simulations being tested with a given set of parameters using 50 *different* random seed values and then determined the average cycle and transient lengths of these simulations.

4.3 Number of Transition Table Entries (T)

Our simorgs are modeled by a finite state automata. The behavior of a finite state automata is determined by a transition table, which defines the behavior of the machine in each possible situation. Since a simorg itself is a finite state machine, we will be using a transition table to specify what action a simorg should take given various stimuli. It is the transition table which gives us diversity of behavior.

The size of a transition table is dependent upon the length of the information string a simorg is processing. As we saw in the last chapter, an information string of bits no larger than decimal four would require 16 different entries in the table. This is a nice sized table to keep track of a simorg's behavior by hand, but does not produce very interesting results. A table of this size with such few behavior possibilities, leads to either the quiescent state or very low cycle lengths after just a couple of time units on the average. When I increased the length of the bit string to 25, I found much more interesting results in the simorgs' behavior. For the first part of the experiment, we used a transition table with 25^2 or 625 different possibilities of behavior. Increasing the number of transition table entries even higher was found to result in only slightly increasing the cycle length and tail lengths of the simorgs as given in Table 4.1. For the rest of my simulations, I went with bit strings no larger than decimal 50 (2500 different behavior possibilities).

Table 4.1: Changes in the number of entries slightly increased the lengths of the cycle and transient lengths on the average using 50 different seed values with $N = 50$, $P = 0.5$, and $\lambda = 0.5$

Number of Entries	Cycle Length	Transient Length
25^2	4.1	12.9
50^2	4.2	13.4
75^2	4.4	13.8
100^2	4.5	14.1

4.4 Number of Simorgs (N)

Because we were not sure of the effects different population sizes would have on our results, we started our simulations with a population of size three. As a result, our initial runs were very simple and easy to understand. Using a community of this size makes it so much easier to detect and correct errors in our code.

Once I had all the bugs worked out, I began experimenting with population sizes of 8, 15, 25, 50, and 100. I ran 50 simulations using different random seed values on each population size and the results turned out very interesting. First off, the actual time it took to complete these simulations varied quite a bit. Population sizes of 8, 15, and 25 each took approximately three hours to complete 50 runs on separate machines. However, it took close to 10 hours for 50 simulations of a community of size 50 and a full day for ones of size 100 to complete. Secondly, as shown in Table 4.2, the average cycle length and transient lengths varied very little overall as the population of the communities was altered.

Table 4.2: Changes in the population resulted in very little variability of the cycle and transient length using 50 different seed values with $T = 50, P = 0.5$, and $\lambda = 0.5$

Population Size	Cycle Length	Transient Length
8	3.7	12.8
15	4.1	12.8
25	4.2	13.3
50	4.2	13.4
100	4.2	13.6

4.5 Changes in the Simorgs' Neighborhood (P)

One nice tool we have for modifying how social or interactive our simorgs will be is the interconnect probability. The interconnect probability determines just how extensive a set of connections will be between other simorgs. A high interconnect probability of 1.0 informs us that each simorg will be heard by all other simorgs, whereas an interconnect probability of 0.0 implies that each simorg will be heard by no one.

We hypothesized at the start of our work that increasing the interconnect probability would result in an increase in the cycle and tail lengths for a given simorg. Before being able to test this hypothesis, it was important to design our simulation so that we could test for this accurately. As we increase the interconnect probability, we not only want to increase the size of a simorg's neighborhood, but we want to be able to build on a simorg's existing neighborhood with new members. That is, we don't want a brand new community of larger size at each increase, but simply additional simorgs added to the community's size from the previous step. This is achieved by preserving the interconnect matrix from the previous time step and simply adding the new neighbors necessary to match the larger interconnect probability. This will allow our simulation to be more realistic.

We tested out our interconnect probability on a community of size 50 with $\lambda = 0.5$ and $T = 50^2$. As shown in Table 4.3 and Figure 4.1 increases in the interconnect probability resulted in increases in both cycle and transient length on the average. It's interesting to think of this as possibly representing the fact that a "hermit" simorg returns to a previous thought sooner than a simorg surrounded by lots of neighbors.

4.6 The Lambda Parameter (λ)

The original motivation for using the lambda parameter stems from the work of Chris Langton who found similar patterns of behavior in complex systems as the lambda parameter varied. In particular, he found a very small region as lambda varied on the interval $[0.5, 0.6]$ of complex structure which showed "the greatest potential for the support of information storage, transmission, and modification, and therefore the emergence of computation" [16]. He referred to this region as a "transition regime" since it was found between periodic and chaotic behavior.

Preceding Langton's work, a scientist named S. Wolfram had begun classify-

Table 4.3: Comparing the average cycle length and transient length of 50 different random seed values of an oral community while varying the interconnect probability

interconnect probability	Avg. Cycle Length	Avg. Transient Length
0.0	2.8	5.2
0.05	2.8	5.3
0.1	2.8	6.9
0.15	2.9	8.5
0.2	2.9	9.1
0.25	3.0	10.3
0.3	3.1	11.2
0.35	3.3	12.0
0.4	3.5	12.7
0.45	3.9	13.1
0.5	4.2	13.4
0.55	4.2	16.0
0.6	4.5	19.8
0.65	4.6	21.4
0.7	4.7	23.9
0.75	5.2	25.2
0.8	5.5	26.7
0.85	6.0	28.0
0.9	6.4	30.2
1.0	7.2	31.3

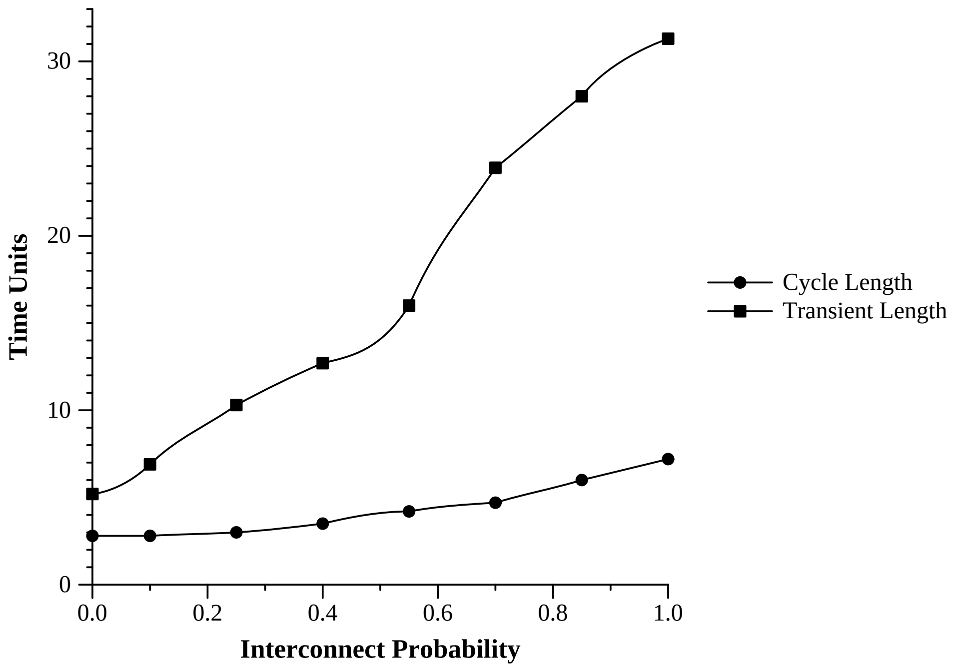

Figure 4.1: A graph showing the cycle length and transient length of an **oral** community as the interconnect probability increases

ing cellular automata into three different classes on the basis of their dynamical behavior. If the period is one, the system has frozen into a static state (Class I), whereas if it is a small number and yields periodic structure, then it is in a tight loop (Class II). If the period is on the the order of the maximum possible, then the system is effectively chaotic (Class III) [17].

Langton was the first to identify the high levels of computation preceding the chaotic behavior and labeled this behavior as Class IV. Here, cellular automata have very long transients and "no direct analog for them has been identified among continuous dynamical systems" [16]. This Class IV behavior of complex activity is where a balance is achieved between stability and flexibility and is the most important to identify. It is here where computation has been found to emerge spontaneously and come to dominate the dynamics of physical systems. Langton felt that life itself had its origin in a phase transition similar to what we see in Class IV behavior:

> Perhaps the most exciting implication is the possibility that life had its origin in the vicinity of a phase transition, and that evolution reflects the process by which life has gained control over a successively greater number of environmental parameters affecting its ability to maintain itself at a critical balance point between order and chaos [16].

We can hypothesize that it was in a phase transition that the numbers of literate persons in ancient Greek society increased sufficiently to allow the Greek Miracle to emerge.

In order for us to see some of these different classes of behavior and find a transition region, we will vary the lambda parameter as Langton did on the interval $[0.0, 1.0]$. Different values of the lambda produce produce different patterns of behavior for the simorgs in our community. If we set it at 0.0, all behavior possibilities lead to the quiescent state, and the entire community goes to sleep in a very short time. This is achieved by modifying all the different possible outputs in the transition table to 0. A lambda parameter of 1.0 leaves the transition table as it is after the randomization of the output entries in the table and produces the most diverse behavior.

I began my investigation of the effects of the lambda parameter by running simulations of the oral community with fifty different seed values and a lambda value of 0.0. I used a population size of 50, an interconnect probability of 0.5, and 50^2 transition table entries. These are summarized in Table 4.4. I got an average cycle length of 1.0 and a transient length of 1.4. This tells us that the community is immediately going to sleep after only 1.4 time units on the average. This make sense since we have a transition table at this point where all the output entries are 0. I continued this process increasing lambda parameter values by 0.05 for each cycle. After running simulations with a lambda parameter of 0.65, I had seen the average cycle and transient lengths slowly increase from 1.0 and 1.4 to 8.2 and

17.4 respectively. This was clearly an example of Class I and II behavior up to this point. The system was either going to the quiescent state (consisting of cells whose final states were all 0), or entering a periodic structure (consisting of cells returning to states of all non-zero or partially non-zero values).

Table 4.4: A summary of the parameters at work in our example simulation

Number of Simorgs = 50
Transition Table Entries = 50^2
Interconnect Probability = 0.5

When the lambda parameter increased to 0.7, the average cycle and transient lengths increased to 270.8 and 215.6 respectively, a significant jump from past increases. As a result, I observed simulations when the lambda parameter increased by 0.01 in the interval $[0.65, 0.78]$. The cycle and transient length slowly climbed to average values of 10.3 and 34.2 after completing simulations with a $\lambda = 0.67$. However, after increasing the lambda parameter to 0.68, I found the system apparently entering Class IV behavior. The average cycle and transient length of the system escalated to values of 184.2 and 441.2 respectively at this point. The average values for the transient length along this interval ranged from 44.6 to as high as 1211.7. The cycle lengths varied from 22.8 to lengths as long as 539.2 time units. Some simulations in this interval went to the quiescent state with a long transient length. This explains some high standard deviation values which are greater than the average cycle length at several lambda parameter values along this interval.

Increasing the lambda parameter to 0.79, led to systems entering a region of chaotic behavior (Class III). For values along the interval $[0.79, 1.0]$, I let the simulations run for 2000 time units. After this point, the system had never returned to a previous state or entered the quiescent state. I simply labeled each of the values as reaching infinity. The results of these simulations can be seen in Tables 4.5 and 4.6. Graphs of these results are shown in Figures 4.2, 4.3, 4.4, and 4.5.

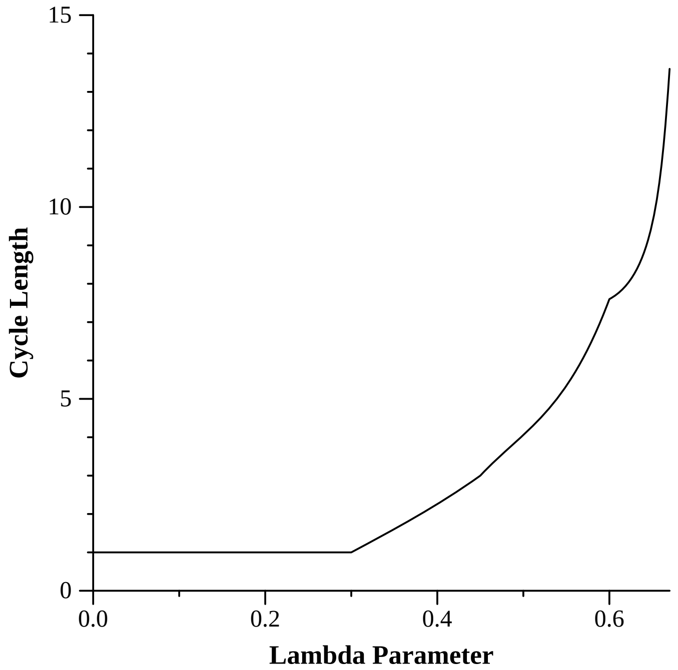

Figure 4.2: A graph showing the cycle length of an **oral** community as the lambda parameter varies over the interval $[0, 0.67]$

Table 4.5: Comparing the average cycle length and standard deviation of 50 different random seed values of an **oral** community while varying the value of the λ parameter

λ parameter	Avg. Cycle Length	Std Deviation
0.0	1.0	0.0
0.05	1.0	0.0
0.1	1.0	0.0
0.15	1.0	0.0
0.2	1.0	0.0
0.25	1.0	0.0
0.3	1.0	0.0
0.35	1.6	1.2
0.4	2.2	1.4
0.45	3.0	2.4
0.5	4.2	4.5
0.55	4.6	6.4
0.6	7.6	14.2
0.65	8.2	15.3
0.66	10.3	18.1
0.67	13.6	24.2
0.68	184.2	358.4
0.69	29.2	39.1
0.7	270.8	342.1
0.71	16.0	126.5
0.72	187.2	358.0
0.73	30.2	40.4
0.74	58.6	99.4
0.75	539.2	777.3
0.76	270.6	359.8
0.77	49.2	167.9
0.78	22.8	19.3
0.79	infinity	—
0.8	infinity	—
0.85	infinity	—
0.9	infinity	—
1.0	infinity	—

Table 4.6: Comparing the average transient length and standard deviation of 50 different random seed values of an **oral** community while varying the value of the λ parameter

λ parameter	Avg. Transient Length	Std Deviation
0.0	1.4	0.4
0.05	2.5	0.6
0.1	3.4	1.1
0.15	3.6	1.5
0.2	3.9	1.6
0.25	4.2	1.7
0.3	4.8	3.0
0.35	7.2	3.6
0.4	7.4	6.1
0.45	9.6	6.6
0.5	13.4	9.3
0.55	16.4	10.2
0.6	17.0	12.1
0.65	17.4	12.2
0.66	26.0	28.9
0.67	34.2	30.4
0.68	441.2	78.6
0.69	95.6	69.3
0.7	215.6	109.9
0.71	73.2	26.8
0.72	775.5	159.9
0.73	73.0	57.6
0.74	44.6	35.7
0.75	1211.7	496.8
0.76	499.3	176.1
0.77	868.0	280.6
0.78	663.3	141.7
0.79	infinity	—
0.8	infinity	—
0.85	infinity	—
0.9	infinity	—
1.0	infinity	—

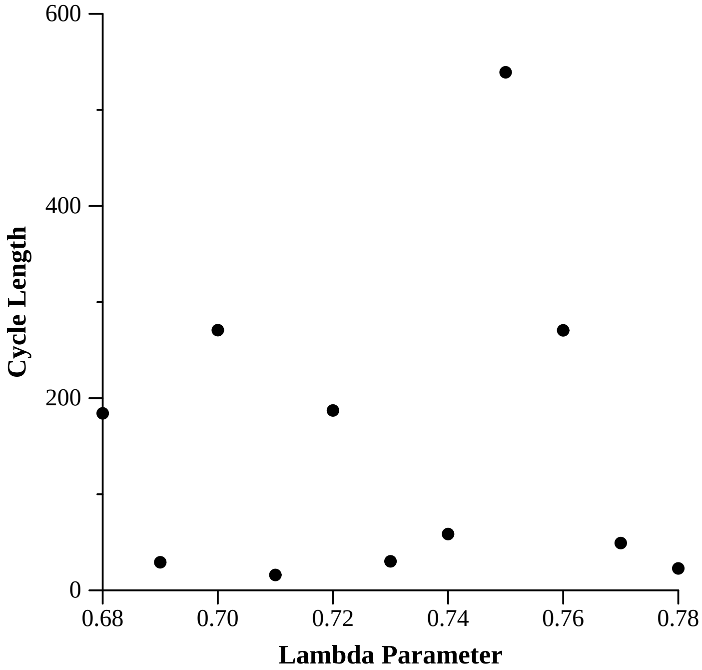

Figure 4.3: A graph showing the cycle length of an **oral** community as the lambda parameter varies over the interval $[0.67, 0.68]$

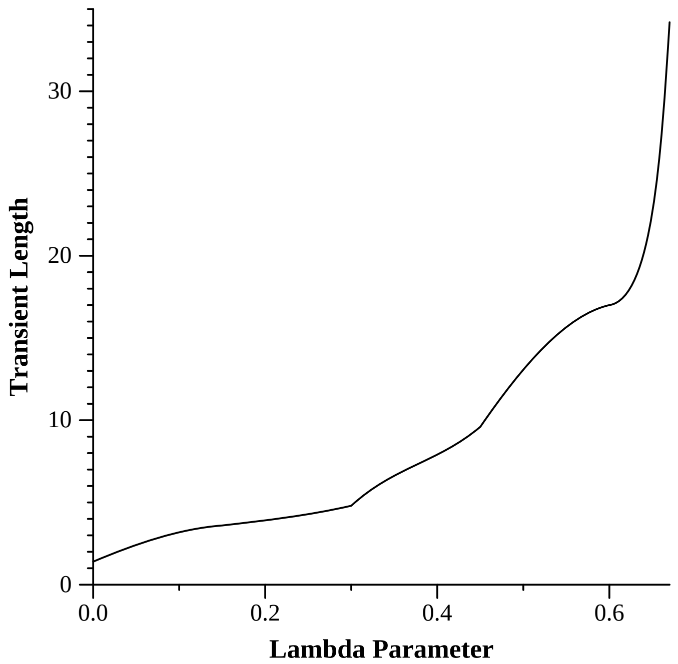

Figure 4.4: A graph showing the transient length of an **oral** community as the lambda parameter varies over the interval $[0, 0.67]$

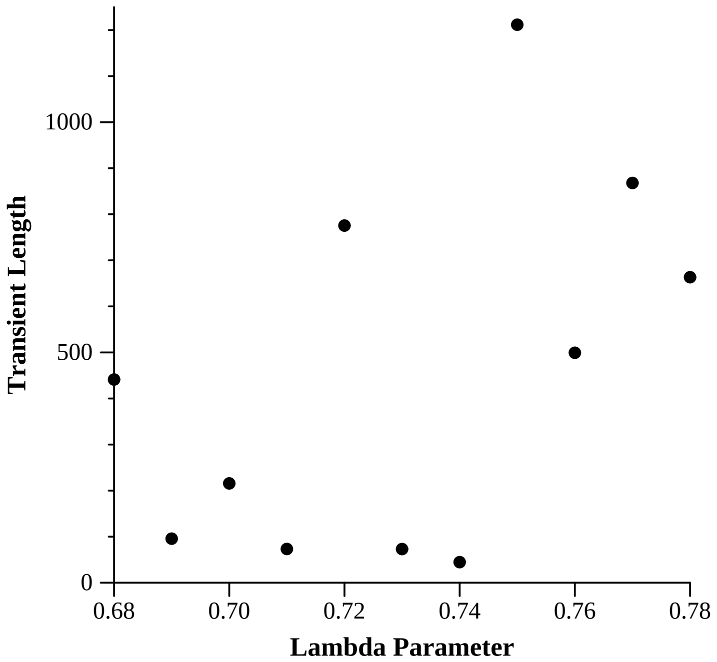

Figure 4.5: A graph showing the transient length of an **oral** community as the lambda parameter varies over the interval $[0.68, 0.78]$

4.7 Looking Closely at the Dynamics of the Community

One way of observing what was happening in the system as the lambda parameter varied with increasing values across the the interval $[0.0, 1.0]$ was to analyze the contents of the community after each time step in each simulation. In Figures 4.6 through 4.17, you can see the buffer contents of a 15 simorg community with $P = 0.5$ and $T = 50^2$ for the duration of a simulation with a particular lambda value. In each of these figures, I used a space if a simorg had a bit string of zero and an asterisk otherwise. This was a way of representing the activity of a simorg. If it was currently hearing, thinking, and speaking something at the end of a simulation three asterisks would be used to represent its current state. So, on the first line of Figure 4.6, for example, you see 45 different buffers at the start of the simulation since we have fifteen simorgs each with hearing, thinking, and speaking buffers. On the second line, are those same buffers after one time unit. All dynamical activity in this example dies out after only one time step. Here, all possibilities of behavior lead to the quiescent state. We can think of this as the fact that all simorgs neither thinking nor speaking anything have eventually led to the entire community becoming bored and going to sleep. It is interesting to observe how the transients slowly increase in length through Figure 4.14 and then increase tremendously as we enter the region at the edge of chaos (Figure 4.15). In this interval, $[0.68, 0.78]$, we find a great deal of complex activity which eventually settles down to periodic behavior after very long transients. Dynamical activity has started expanding rather than contracting with time in this interval. In Figure 4.17, fully developed chaotic behavior has become apparent after only several time steps. Here, the activity never shows any period or pattern. The simulations with lambda values along the interval $[0.78, 1.0]$ all exhibited this type of behavior and, after never returning to a previous state for a period of 2000 time units, were stopped and labeled as going to infinity. It should be noted that, unlike the other figures, Figures 4.15 through 4.17 do not represent the complete run of the simulation. They are simply a snapshot of the community after the first 50 time steps. One would need several pages to show each of these systems through completion since these simulations ran for hundreds of time units before entering a cycle. The important thing to note in each of these figures is the high concentration of activity present. So, we can conclude along the same lines as Langton that the progression of dynamical behavior as a function of λ in complex systems is:

$$\text{fixed-point} \rightarrow \text{periodic} \rightarrow \text{complex} \rightarrow \text{chaotic}.$$

In terms of Wolfram classes, we have:

$$I \rightarrow II \rightarrow IV \rightarrow III$$

[17].

Figure 4.6: A community of 15 simorgs with $\lambda = 0.0$

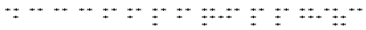

Figure 4.7: A community of 15 simorgs with $\lambda = 0.1$

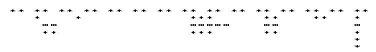

Figure 4.8: A community of 15 simorgs with $\lambda = 0.2$

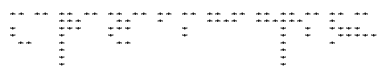

Figure 4.9: A community of 15 simorgs with $\lambda = 0.3$

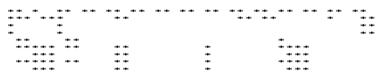

Figure 4.10: A community of 15 simorgs with $\lambda = 0.4$

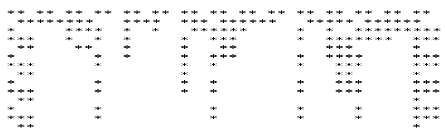

Figure 4.11: A community of 15 simorgs with $\lambda = 0.5$

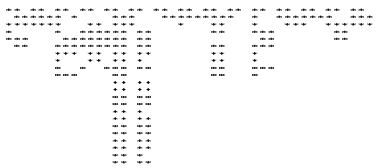

Figure 4.12: A community of 15 simorgs with $\lambda = 0.6$

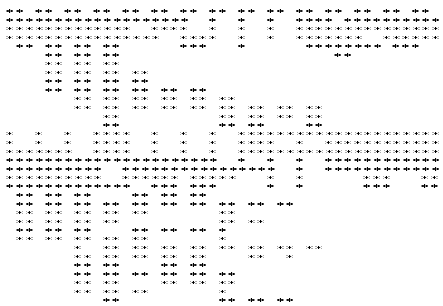

Figure 4.13: A community of 15 simorgs with $\lambda = 0.65$

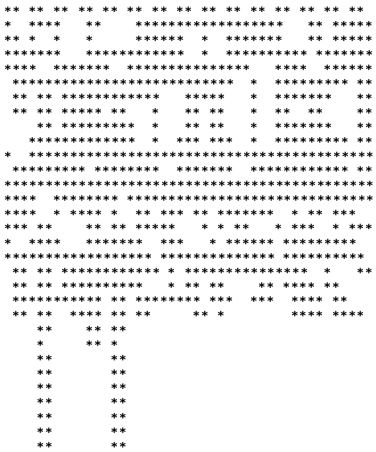

Figure 4.14: A community of 15 simorgs with $\lambda = 0.67$

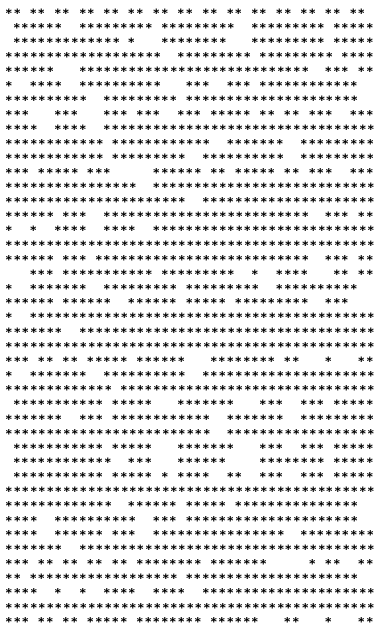

Figure 4.15: A community of 15 simorgs with $\lambda = 0.68$ after 50 time steps

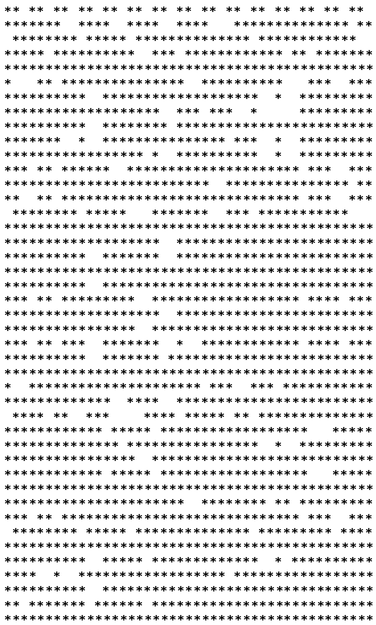

Figure 4.16: A community of 15 simorgs with $\lambda = 0.78$ after 50 time steps

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Figure 4.17: A community of 15 simorgs with $\lambda = 1.0$ after 50 time steps

Chapter 5

Simulating Literacy

5.1 Introduction

After completing our study of the dynamics at work in an oral community, we had laid the groundwork for our study of a literate community. In this chapter, we want to explain the setup of our literate community and compare the results we found varying the lambda parameter with those in our oral community. In addition, we will explain an experiment we ran comparing an alphabetically literate population with one which is hieroglyphically literate. In each these populations, illiterate simorgs have the opportunity to become literate and we'll explain exactly how this occurs and the results we found.

5.2 A Literate Community

A literate simorg will be a simorg which has the ability to read and write. That is, it will be able to recognize and interpret data in a reading buffer and respond by inserting data into a writing buffer. Literate simorgs therefore have an additional internal and external state. By definition, we'll allow a literate simorg to choose between either reading or hearing input and either producing writing or speech as output. This makes more sense since a person is not usually listening to information and reading at the exact same time. The same goes for writing and speaking. An illustration of a literate simorg can be see below in Figure 5.1.

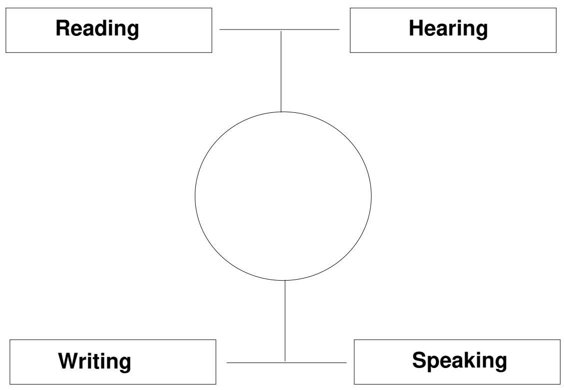

Figure 5.1: The genetic makeup of a literate simorg. It contains two buffers illiterate simorgs do not have — one for reading and one for writing.

Once a literate simorg in our community begins writing (inserting a bit string into its writing buffer), this value is copied to the reading buffer of all the simorgs it is connected to. If a literate simorg chooses to speak, rather than to write, the data being spoken is copied into the hearing buffers of each of its neighbors just like in the oral simulations. In addition, we'll be using the same set of parameters and determining the literate simorg's behavior solely by a transition table as we've done in the past.

In a sense, our literate simorgs can be thought of as having "free will." That is, they get to decide whether they want to read or hear and then write or speak. In actuality, these are boolean values determined at random where the probability of a simorg choosing one over the other is 50–50. It should be noted that we have introduced some nondeterminism into our simulation at this point. However, before granting the simorgs the free will to choose their desired input or output, a more deterministic model was investigated first. I had actually built into each of the simorgs' "genes" a sequence of boolean values that would determine the sequence of actions to take with respect to the input and output buffers. The results I obtained running the simulations involving changing values of λ were identical to those in which the simorgs have free will. So, I decided to go with the former setup, since this gave the simorgs more individuality.

I began my experiments on literate populations by investigating the effects of varying lambda parameter values on a literate population. I was interested in determining its effects on the cycle and transient lengths in comparison to the effects it had in the illiterate simulations. In addition, I was very curious if we would see the same "edge of chaos" region as we had in the past. Once again, I ran simulations with 50 different seed values and averaged the results. I used all the same parameters as I had used in the illiterate experiments including the same 50 seed values. The results and graphs of these experiments can be seen in Tables 5.1 – 5.2 and Figures 5.2 – 5.5.

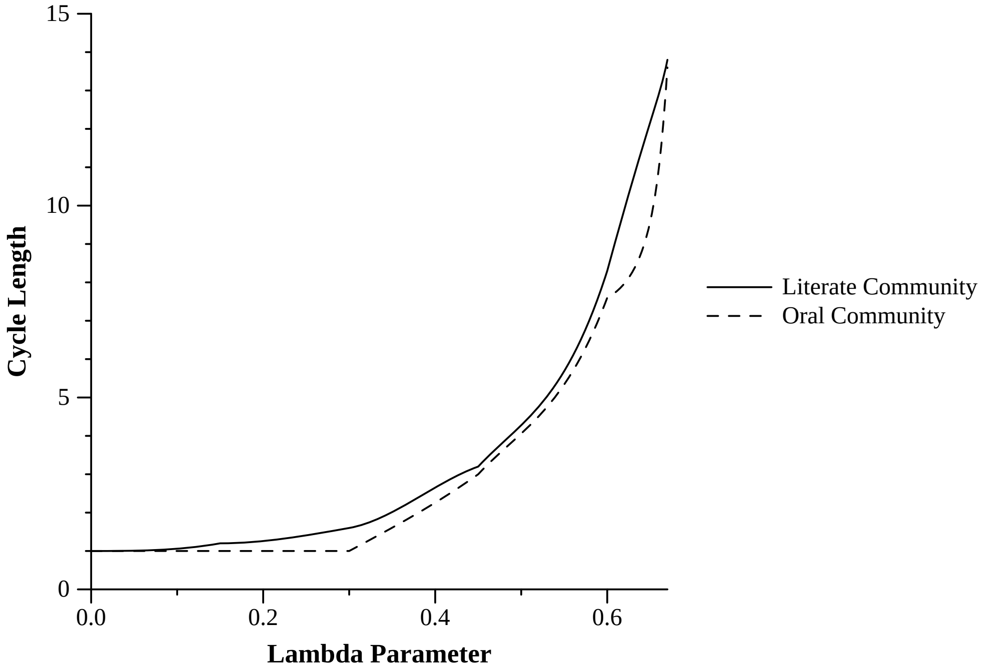

Figure 5.2: A graph showing the cycle length of a **literate** community as the lambda parameter varies over the interval $[0, 0.67]$. The graph of from the oral community is also shown with a dashed line.

One of the first differences I noticed after I started running my literate simulations was in the actual amount of machine time it took to complete 50 simulations. It took approximately 10 hours to complete 50 different simulations of an oral community. With a literate community, it was taking close to 15 hours to complete 50

Table 5.1: Comparing the average cycle length and standard deviation of 50 different random seed values of a **literate** community while varying the value of the λ parameter

λ parameter	Avg Cycle Length	Std Deviation
0.0	1.0	0.0
0.05	1.0	0.0
0.1	1.0	0.0
0.15	1.2	0.4
0.2	1.2	0.4
0.25	1.4	0.5
0.3	1.6	1.2
0.35	1.8	1.7
0.4	2.8	2.6
0.45	3.2	4.4
0.5	4.4	4.5
0.55	4.8	7.2
0.6	8.3	15.5
0.65	12.4	21.8
0.66	12.7	24.3
0.67	13.8	34.5
0.68	184.8	367.8
0.69	37.2	122.2
0.7	403.2	798.4
0.71	400.8	799.6
0.72	300.2	724.8
0.73	408.5	349.2
0.74	821.4	863.0
0.75	126.2	167.6
0.76	279.3	240.0
0.77	600.4	123.3
0.78	88.9	199.2
0.79	infinity	—
0.8	infinity	—
0.85	infinity	—
0.9	infinity	—
1.0	infinity	—

Table 5.2: Comparing the average transient length and standard deviation of 50 different random seed values of a **literate** community while varying the value of the λ parameter

λ parameter	Avg. Transient Length	Std Deviation
0.0	1.8	0.4
0.05	3.0	1.6
0.1	3.6	1.8
0.15	4.4	1.8
0.2	5.0	2.1
0.25	6.6	3.0
0.3	7.8	3.9
0.35	8.0	4.6
0.4	11.0	6.4
0.45	11.8	8.3
0.5	15.4	8.7
0.55	17.6	12.9
0.6	27.0	18.5
0.65	32.4	22.2
0.66	47.0	41.3
0.67	52.4	57.6
0.68	464.6	771.0
0.69	123.8	132.7
0.7	471.6	230.2
0.71	82.8	62.1
0.72	1095.2	724.6
0.73	96.2	62.4
0.74	51.6	37.6
0.75	1216.4	526.0
0.76	599.2	130.7
0.77	916.4	159.8
0.78	691.4	102.8
0.79	infinity	—
0.8	infinity	—
0.85	infinity	—
0.9	infinity	—
1.0	infinity	—

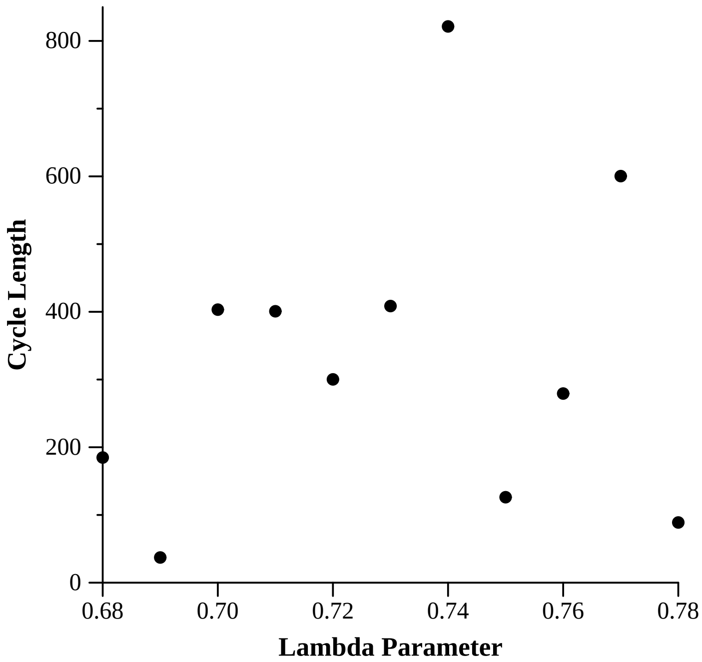

Figure 5.3: A graph showing the cycle length of a **literate** community as the lambda parameter varies over the interval $[0.68, 0.78]$

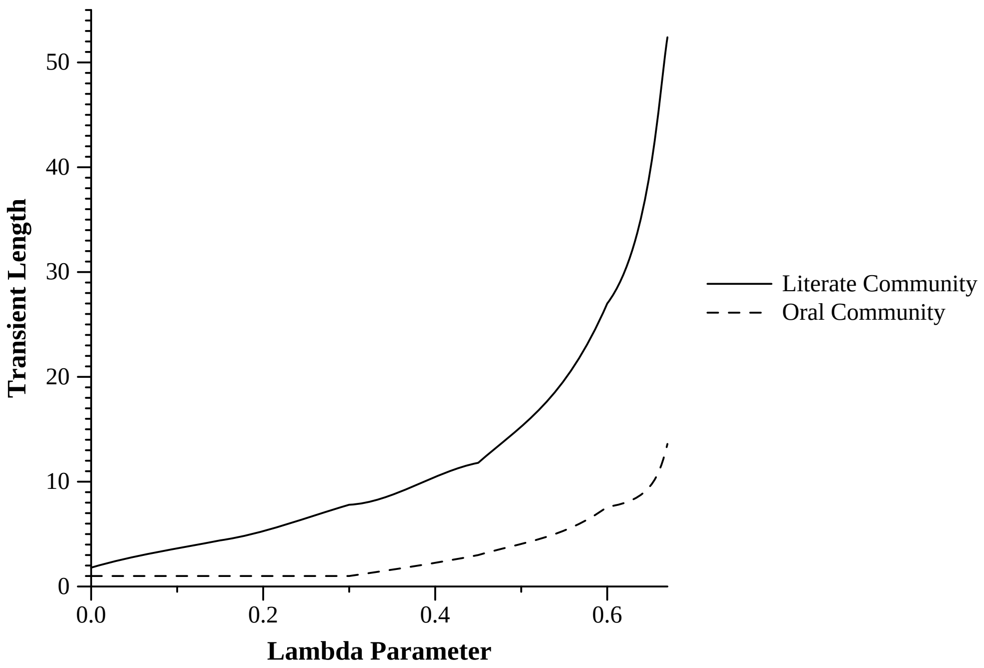

Figure 5.4: A graph showing the transient length of a **literate** community as the lambda parameter varies over the interval $[0, 0.67]$. The graph from the oral community is also shown with a dashed line.

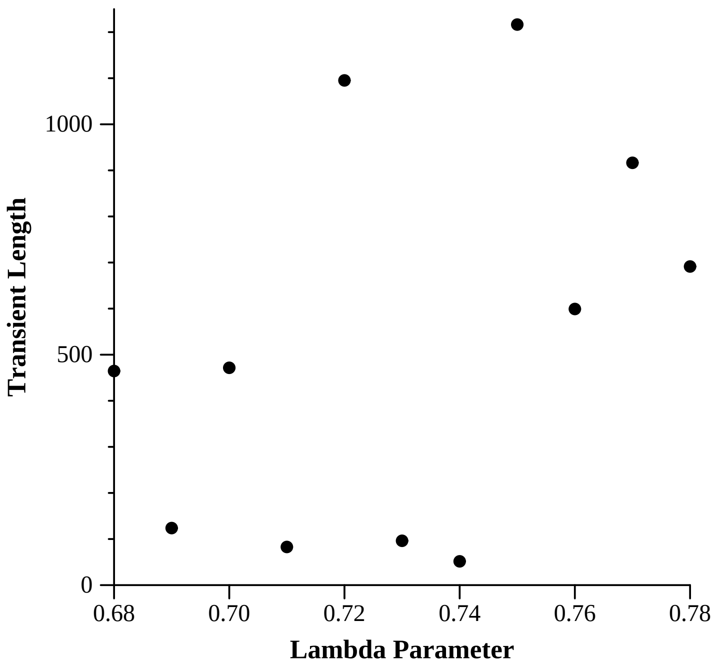

Figure 5.5: A graph showing the transient length of a **literate** community as the lambda parameter varies over the interval [0.68, 0.78]

runs. This led me to believe we were most likely getting longer transient lengths in our literate simulations.

My hunch turned out to be correct. The lengths of the cycles and the amount of time it took to reach a cycle were larger than in the oral community. In addition, just as we saw in the oral community, the average cycle and transient lengths were directly proportional with lambda values along the interval $[0.0, 0.67]$. The entrance to the edge of chaos was smack dab at the same spot as we had seen before and it lasted through the value 0.78. The lengths of the cycles in this Class IV region reflected the same erraticism as in the past. Chaos commenced at $\lambda = 0.79$ as we had seen in the past as well.

5.3 Two Literate Communities — One Alphabetic, One Hieroglyphic

One very interesting final experiment we got to test was a comparison of two separate literate populations. In the first population, we would be studying the effects of alphabetic literacy. In the second, hieroglyphic literacy would be studied. We wanted to start out with two populations of the same size in both simulations where a specific percentage were literate and the rest were not. So, we would have two separate populations where both oral and literate communication were in action. The interesting twist to these simulations is that an illiterate simorg has the ability to become literate after being apprenticed by a literate neighbor for a certain period of time. The apprenticeship must take place between neighbors, one of which is already fully literate. So, a simorg which is not connected to anyone at the start of the simulation (which we'll call a hermit) will remain illiterate if they were not labelled literate at the start of the simulation.

Everything will be identical in both simulations, except that the time it takes an illiterate simorg to achieve hieroglyphically literacy will be ten times the amount of time it takes to achieve alphabetically literacy reflecting the ease in learning an alphabet over a script with thousands of characters and no vowel sounds.

In our simulations of these separate populations, we added an additional parameter known as the *literate probability*. This parameter represented the probability that a given simorg would be literate at the start of the simulation. In my tests, I set this value to 0.1 and ran simulations using populations of size 50. This meant that we started out with 5 simorgs determined at random in each population which would be labelled literate.

In the first experiment of these two separate populations, I wanted to examine how the literacy rate of the populations changed with respect to the time units passed. I decided to investigate this using a lambda parameter of 0.71 along with the same parameters as I had used in my literacy simulations. I recorded the percentage of the population that had become literate after every 10 units in the alphabetic population and the percent literate in the hieroglyphic population after 100 units in 50 different simulations. The results can be seen in Tables 5.3 – 5.4 and Figure 5.6.

Table 5.3: Comparing the percentage of **alphabetic** literates with respect to time units completed.

Time Units	% Literate
0	10.0
10	25.2
20	52.0
30	80.6
40	90.0
50	98.8
⋮	⋮
420	98.8

Table 5.4: Comparing the percentage of **hieroglyphic** literates with respect to time units completed.

Time Units	% Literate
0	10.0
100	25.2
200	52.0
⋮	⋮
240	52.0

The alphabetically literate population achieved an average maximum literacy rate of 98.8% after only 50 time units. This population ran on the average for 420 time units. The hieroglyphically literate population achieved an average maximum literacy rate of 52.0% after 200 units. This population ran on the average for only 240 time units, a significant difference compare to the alphabetically literate population. This factor combined with the difficulty in achieving hieroglyphic literacy resulted in this population failing to achieve high rates of literacy.

Using the same parameters, I next ran 50 simulations at each lambda parameter value for both populations. I recorded the percentage of the population that had achieved literacy at the point when the simulation ended and then averaged

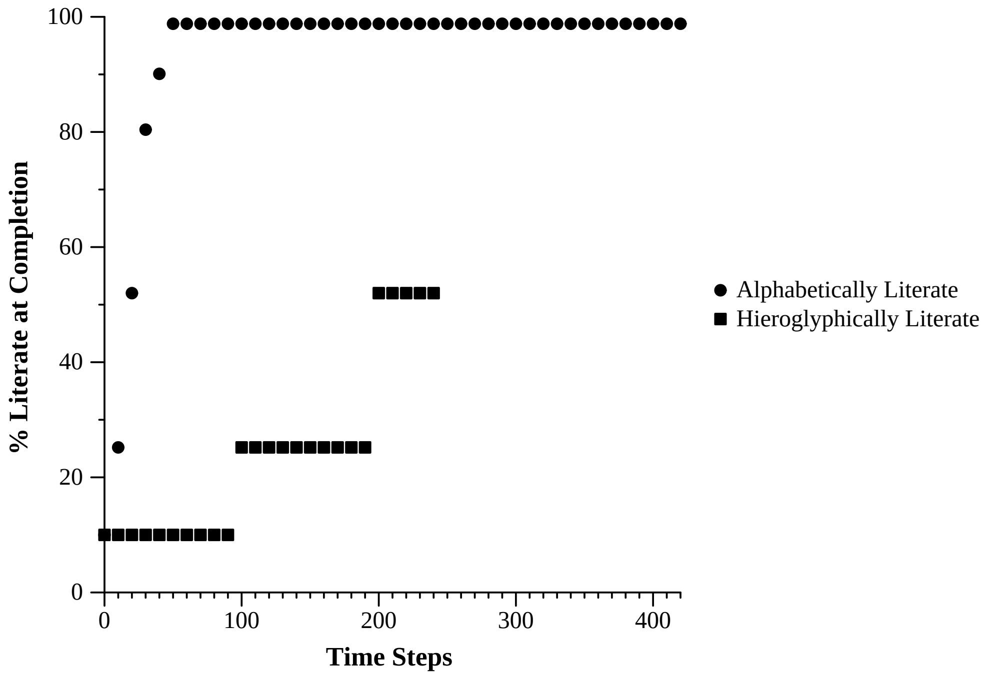

Figure 5.6: A comparison of two literate populations as the number of time steps increases.

these values in both populations. These results can be seen in Table 5.5 and Figure 5.3.

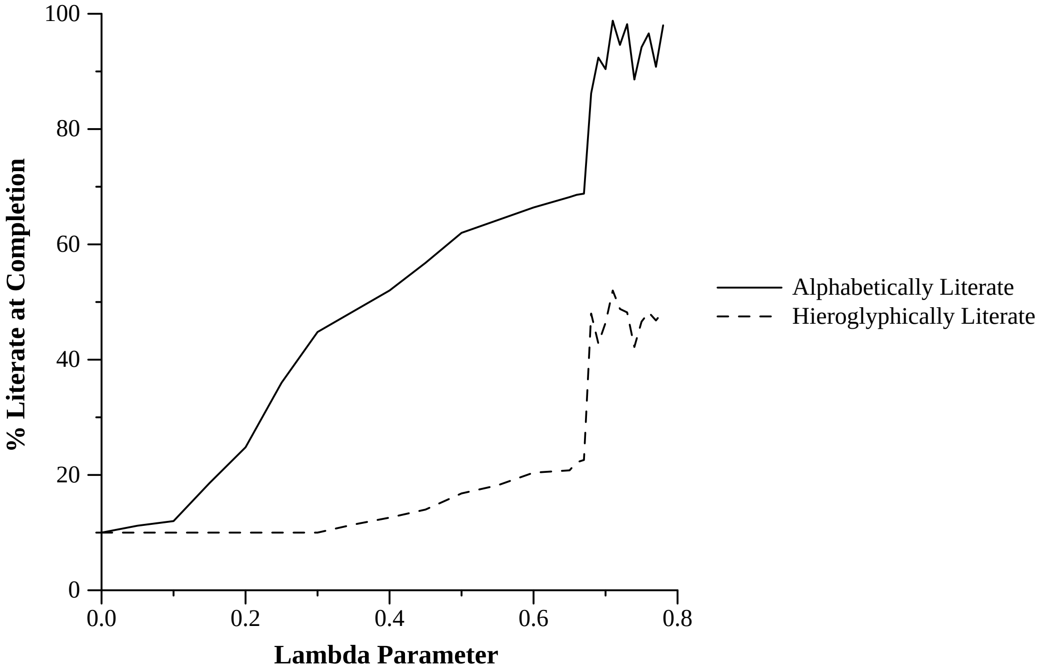

Figure 5.7: A graph to compare the results found when simulating two separate literate populations — one which uses an alphabetic script and one which uses a hieroglyphic script. Both populations started out with only 10% of the population as literate and this graph reflects the final percentage at the completion of a run with the lambda values along the interval $[0.0, 0.78]$. The interval $[0.78, 1.0]$ went to infinity for all lambda parameter values tested.

It is clear here that alphabetic literacy is spreading at a much higher rate throughout the population. Most interestingly, as both populations entered the region at the edge of chaos, the final percentage of the population that had become literate shot up dramatically. In fact, at several lambda parameter values in the alphabetically literate population, I got populations which had become completely

Table 5.5: Comparing the percentage of literates in two literate populations with respect to the λ parameter

λ parameter	Alphabet	Hieroglyphics
0.0	10.0	10.0
0.05	11.2	10.0
0.1	12.0	10.0
0.15	18.6	10.0
0.2	24.8	10.0
0.25	36.0	10.0
0.3	44.8	10.0
0.35	48.4	11.4
0.4	52.0	12.6
0.45	56.8	14.0
0.5	62.0	16.8
0.55	64.2	18.2
0.6	66.4	20.4
0.65	68.2	20.8
0.66	68.6	22.2
0.67	68.8	22.6
0.68	86.2	48.0
0.69	92.4	42.8
0.7	90.4	46.4
0.71	98.8	52.0
0.72	94.6	48.8
0.73	98.2	48.8
0.74	88.6	42.2
0.75	94.2	46.6
0.76	96.6	48.8
0.77	90.8	46.8
0.78	90.8	46.8

literate.

Chapter 6

Conclusion

6.1 Putting our Results in Perspective

This thesis is in a way a first step or pilot study toward investigating the role alphabetic literacy may have played in The Greek Miracle. We are dealing with a collection of very simple cellular automata here which are difficult to relate to actual populations. However, there always must be those first steps or seeds that must be planted first in order to begin learning, exploring, and hypothesizing what may be occurring on a larger scale.

From our experiments using two separate literate populations, we can hypothesize that it was in that region of complex activity at the edge of chaos that the Greek Miracle occurred. This region where lambda varied along the interval $[0.68, 0.78]$ was where we had clearly found computation to emerge and the storage and transmission of information to be at its maxim. We can also hypothesize that it was the ease in learning the alphabet script that led the Greek culture to blossom in such a short time period. The hieroglyphic populations may have reached a similar miracle, but it would have taken much longer. We don't know for sure that the alphabet was indeed the "explosion" the led the Greeks into the Golden Ages, since our oral communities exhibited a similar jump in dynamical activity at the same point. However, I feel the true answer as to the real cause(s) lies in that region "on the edge of chaos" and should be investigated further.

6.2 Looking Ahead

There are a lot more different experiments and investigations of *SimLit* that can be done. One interesting one would be to set up a population where you have simorgs training in both alphabetic and hieroglyphic literacy at the same time. Another area that can be explored is implementing a "store" for each literate simorg where it can store tablets for reading and writing. This would be like a personal library for each simorg. The tablets ("simtabs") could be sent to neighboring literate simorgs for processing. You could implement the death and birth of simorgs here as well and allow ancestors to inherit their predecessor's store, but not memory.

Another experiment involves further investigating oral societies as compared to literate ones. One fact of finite automata systems is that you will see longer cycle lengths and less complexity given the additional internal and external state variable in the transition table. It would be interesting to see the results if we performed checksums based solely on the simorgs' thinking buffers rather than including the other internal and external state variables as well. Comparing the cycle and transient lengths of these simulations would give us a more accurate view of the differences between these two populations.

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Vita

Andrew Douglas Digh was born in Gastonia, North Carolina on March 25, 1970. He graduated from Gaston Day School in Gastonia in May 1988 and received a Bachelor of Arts degree in Mathematics from the University of North Carolina at Asheville in May 1992. He entered the University of Tennessee at Knoxville in August 1992, and received a Master of Science degree in Computer Science in December 1994. While in the Master's program, he served as a graduate teaching assistant in introductory computer science and an instructor in electronic printing and graphics. Beginning the spring of 1995, he will enter the Doctor of Philosophy program in Education here at UT.