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Generative replication and the evolution of complexity

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ABSTRACT

This paper identifies generative replication as a form of replication which has the potential to enhance complexity in social and biological evolution, including the wondrous complexity in the biological world, and complex social institutions such as human language and business corporations. We draw inspiration from the literature on self-reproducing automata to clarify the notion of information transfer in replication processes. To enhance complexity, developmental instructions must be part of the information that is transmitted in replication. In addition to the established triple conditions of causality, similarity and information transfer, a generative replicator involves a *conditional generative mechanism* that can use signals from an environment and create developmental instructions. We develop a simple model, a one-dimensional linear automaton that is consistent with our four proposed conditions for a generative replicator. We show that evolution within this model will indeed approach maximal complexity, but only if our four proposed conditions are not violated.

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When does replication lead to greater complexity? As the origin of complex forms of organization is one of the most fundamental problems in science, this question is of considerable importance, in particular in the natural sciences. It is a more recent concern in the social sciences (Rosser, 2009) where much prior effort has been directed at understanding how agents are able to *cope* with complexity (Blau and McKinley, 1979; Brown and Eisenhardt, 1997; McQuiston, 1989; Weiss, 1982). As recent contributors to the literature on complexity in the social sciences (Rosser, 2009), we believe that the question of origins and evolution of complex social institutions should be at the center of attention.[1]

The goal of this paper is to offer a novel perspective on replication processes that can potentially explain why evolution sometimes leads to dramatic gains in complexity—and sometimes leads nowhere. We explain what kind of replicating entities are required to increase the complexity of an evolving social or biological population. These special replicators are referred to as generative replicators. Examples include routines, and, of course, genes. We formulate four axioms that jointly lay out the necessary and sufficient conditions for the existence of generative replication. Our argument is supported by a formal model drawn from the field of automata studies (von Neumann, 1966; Sipper, 1998; Freitas and Merkle, 2004).

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One of the triumphs of the modern theory of evolution is that it can explain the origins of very complex living things (Dawkins, 1986). A process characterized by the general Darwinian principles of variation, selection and inheritance (or replication) can over longer periods of time lead to amazing increases in complexity. The canonical example is the evolution of the human eye. Even if its complex design suggests the presence of a superior creative force, we know that the eye emerged because of accumulated gradual transformations over long periods of time.

Social evolution has led to increases in cultural complexity that can be compared to the evolution of the human eye. Through very long periods of time, we can observe the emergence of increasingly complex social institutions and organizations starting from the evolution of pre-linguistic culture, human language, and tribal customs, to writing and records, states and laws, and the institutionalization of science and technology. Each new transition in the evolution of culture has retained core features of prior developments and then added a new layer of complexity. Indeed, there seems to be no end to the increase in complexity in the social world.

The process of replication is central to explaining the increase of complexity that has happened during the course of social and economic evolution. Replication involves transfer of information caused by a source so that the copy is similar to the original. Many forms of replication have this signature, including copying with sound recorders, photocopiers, nests and burrows. But in order to increase complexity one more condition must be fulfilled. We argue that there must be a transfer of a construction mechanism that can create a new entity on the basis of a fairly simple set of instructions.

Rather than copying all the details of the fully scaled-up entity, the transfer of information can be compressed. Genes allow transfer of information in compressed form. A gene is a biological example of such a conditional generative mechanism. All such mechanisms have the potential to generate new copies conditional on the input signals they receive from their environment. Replicators that reliably transfer conditional generative mechanisms can enhance complexity, but replicators that are beset with copy error cannot. Since it is obviously important to identify replicators that can enhance complexity, we reserve the term “generative replicators” to describe them.

Habits and routines are the most obvious examples of generative replicators in the social context. A habit is a disposition to engage in previously adopted or acquired behavior, triggered by an appropriate stimulus. Habits replicate indirectly, by means of their behavioral expressions. They can impel behavior that is followed by others, as a result of incentive or imitation. Eventually, the copied behavior becomes rooted in the habits of the follower, thus transmitting from individual to individual an imperfect copy of each habit. Routines are organizational dispositions made up of habits that are developed in an organizational context.

It is important to note that habits and routines are characterized as dispositions (or propensities)—they reliably map particular input signals onto particular behaviors. While the observable behavior is a signature of habits and routines, its core is the cognitive component that maps the reading of cues onto behavior. It is the possibility of replicating the underlying cognitive component that gives habits and routines status as generative replicators.

A concrete example of a persistent cognitive component of a routine is useful. The routine in question evolved in the military (Morison, 1966). Because of shortage in supplies of armaments during WWII, a piece of light artillery was hitched to trucks and then served as mobile coast defense. Even if the new device worked, the rapidity of fire was thought to be rather slow. Various experts looked into the matter and noticed a strange interruption each time the gun was fired. The crew simply ceased all activity and came to attention until the gun had been discharged. This routine considerably slowed down the rapidity of fire, but no one had a clue why it occurred. Eventually, an old colonel solved the riddle (Morison, p. 17):

> “Ah,” he said when the performance was over, “I have it. They are holding the horses.”

To be sure, it was a gun that had been used 60 years before in the Boer wars. At that time, it was important to hold the horses during gun fire, but by the 1940s the horses were long gone. Had the old colonel not been around, it is doubtful if anyone would have understood what happened. Even while the context had changed in dramatic ways, the underlying cognitive component of the routine had somehow replicated across generations of soldiers. The event of gun fire reliably triggered an observable behavioral trait among members of a crew that operated the gun many years after the horses were relieved from duty.

This example illustrates how routines can function as generative replicators. The gun firing routine had been reliably replicated through the regimen of drilling recruits on parade fields. During endless repetition of behavior, the cognitive component of the routine was also transferred, but had gradually faded beyond conscious awareness.

Generative replication is a natural construct for analyzing routines over the long term. By long term we refer to evolutionary dynamics that unfolds over decades and centuries. But our argument also has important implications for the typical empirical (case) studies of routines that span a few years or even shorter periods of time. We find that generative replication can involve two kinds of error that are both prominent in social and economic evolution. The first is copy error. Copy error changes the cognitive component of a routine so that input signals are associated with new forms of behavior. Within the context of our previous example, a copy error might associate the firing of a gun with all kinds of behavior. We find that anything but the smallest dose of this form of error is absolutely detrimental to the evolution of complexity. The second form or error is when the generative replicator misreads instructions. Read error changes behavior, but not the cognitive component. This kind of error erodes order in the observable trait pattern, but retains the underlying replicator. Without copying error, the cognitive component would reliably be replicated across time even with significant read error and notable disorder in observable patterns of behavior.

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