

December 2007

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## Recommended Citation

Vitzthum, Sascha, "Dissemination of Culture in a Networked World: The Influence of Network Structure on the Outcomes of the Axelrod Cultural Model" (2007). *AMCIS 2007 Proceedings*. 413.  
<http://aisel.aisnet.org/amcis2007/413>

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# DISSEMINATION OF CULTURE IN A NETWORKED WORLD: THE INFLUENCE OF NETWORK STRUCTURE ON THE OUTCOMES OF THE AXELROD CULTURAL MODEL

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## **Abstract**

*This paper investigates the effect of network structure properties on the outcome of a well researched information dissemination mechanism. Using a computer simulation, the impact of network transitivity, centralization and density on both process variables and final outcomes are tested. The key finding of this simulation include a process model where the network structure properties only influence the velocity of convergence, which in itself influences the final outcome of the convergence mechanisms (final number of cultures).*

**Keywords:** Axelrod Culture Model, Social Network, Diffusion of Innovation, Dissemination of Information, Network Analysis, Simulation model,

## Introduction

The Axelrod Cultural Model (ACM) is one of the most prominent research ventures in to the realm of dissemination of culture using computer simulation. The basic premise of the ACM is that actors who share similar cultural attributes, which include language, beliefs attitudes and behaviors, are more likely to interact and further adapt each other's values, thus forming a homogenous shared culture in the long run (Axelrod, 1997).

The original model consisted of 100 agents, with 5 features which each can have one of 10 traits. Thus, an agent's culture is described as a 5 digit string (i.e. 4, 3, 5, 9,1). Axelrod used a geographical distribution of the agents on a 10 by 10 grid. The premise of the simulation was that actors could only interact with their immediate (up to four) neighbors. Once an agent is activated, it can only exchange a feature if at least one of the traits is of equal value. Thus, the more traits are in common the higher the chance of exchange. Conversely, if there are no common traits, an exchange cannot take place.

The main outcome of the ACM is that regardless of how the different parameters are manipulated, stable cultural regions emerge. The median number of stable regions was 3. However, 14% of the runs yielded only one stable region, whereas 10% of the runs resulted in more than six regions. The original paper also suggests that the number of stable regions is depended upon the range of interactions or the size of the neighborhood. Axelrod showed that the average number of stable regions increases as interaction of grater distances occur. For small neighborhoods (4 neighbors), the average number of stable regions was 3.4, whereas large neighborhoods (12 neighbors) yielded an average of 1.5 stable regions. Given the small sample size of the experiments, other researchers investigated this relationship and extended the research.

## Theoretical Background

### *Extensions of the ACM: Investigating the Effects of Interaction Ranges*

There are several extensions of the ACM that are concerned the increase of interaction ranges and its effect on cultural homogeneity. Shibanaï et al. (2001) investigated the effect of a global mass media and modeled it as a "generalized other" which acts as a direct neighbor to each agent. Their experiment showed that a global agent can speed up the convergence of cultures while at the same time yielding a smaller number of distinct cultures at the end of the simulation.

Greig (2002) also investigated global impacts on the number of stable regions. Similar to the original ACM, Greig increased the number of potential neighbors and ran simulations for discrete levels of neighborhood sizes. He investigated the effect of range by introducing 6 levels of sizes varying from the 4 to 99 neighbors. He replicated the ACM hypothesis that with increasing number of neighbors, the average number of stable regions decreases. Using 20000 activations per run, he observed that the original model yields an average of 4.1 unique cultures. For any bigger neighborhood size, the number of cultures dropped below 1.5. Most of his runs yielded quasi homogeneity with an average of 99.15% of the agents belonging to the dominant culture. Ward (2006) introduced the concept of virtual neighbors to the ACM model. Her model showed that an increase in access to global communication and thus to virtual neighbors, decreases the number of unique cultures over time. However, in one scenario where communication was only with virtual neighbors, she found that the decline of cultures did not occur in the predicted manner. In contrary, with purely virtual communication in place, more cultures survived.

Overall, two generalizations can be drawn from the previous research: With the grid structure in place, the increase of range leads to fewer distinct cultures once the system converges. Initial similarity or a constant source of influence will lead to more distinct cultures in the system. In other terms, similarity leads to diversity through the creation of boundaries, while range influences the size of the distinct territories.

### *Investigating the Impact of Network Structure*

Building on the findings of previous research, an important question to be raised: Assuming that virtual communication becomes more important, will the geographically based models still hold true? In other words, will the decline of cultures still occur, if the assumptions of the model are modified to present a virtual world?

In his famous work on the diffusion of innovations, Rogers (2003) showed the importance of social structures and included communication networks on the diffusion of information. Mirroring the ACM research, Rogers (2003) generalized that homophily and communication proximity within network increase the likelihood of the diffusion of shared ideas. However, he also recognized that those two factors decrease the chance of novel information being distributed within the communication network. According to this theory, the setup of the ACM on a grid, where communication proximity equals geographical proximity, has to lead the diffusion and eventual dominance of a few shared cultures rather than to a diverse system of many diverse and novel cultures. Looking at the ACM from a network perspective it the spatial grid seems to be an extreme case of a network structure.

In the next section we will identify the extreme values in terms of network measures such as network transitivity, network centralization and network density, and develop hypothesis that generalize the impact of network structure process variables, which in turn influence the outcomes of the ACM. The first set of hypothesis is distinct from previous research. Rather than predicting the final outcomes in terms of number of final cultures or size of the dominant cultures, the measures of the network structure are predicted to influence the process variables of the simulation: time to conversion and activations until convergence. The second set of hypotheses is aimed at understanding how the process measure of convergence velocity will influence the final outcomes of the converged systems.

## Research Model

### *The Impact of Network Antecedents on Process Measures*

Granovetter demonstrated that weak ties between different personal networks can enable the diffusion of unique information. Drawing on the theory of weak ties (Granovetter 1973), Rogers suggested that an imbalanced distribution of communication ties within the network can lead to the emergence of more novel ideas. Rogers recognized that the emergence of the Internet increased the availability of personal networks with weak ties (Rogers 2003, Rosen 2000). The strength of ties is based on the of transitivity score of the network. Transitivity is usually defined as the proportion of transitive triplets in a network. High transitivity indicates a high degree of reciprocity. Generally speaking, a low transitivity indicates the existence of weak ties, whereas a dominance of strong ties results in more transitive networks. The original ACM has transitivity of 0 and thus an abundance of weak ties which in turn leads to more dissimilarity among cultures. Recalling the basic exchange mechanism of the ACM, this dissimilarity should yield more activations before the system is converged in a quasi homogenous state.

*Hypothesis 1a: The transitivity of the network will have a negative impact on the total number of agent activations.*

Centralization is another statistic that describes the linkages within a network. In particular, it measures the extent to which actor centralities vary within a system. (Wassermann & Faust 1999). If, for example, one actor is connected to all other actors, while the other actors do not share connections among themselves the centralization of the network is 1. On the contrary, if actors share the same amount of connections (as with the ACM model) centralization is 0. In the social network analysis literature (Cook et al. 1983) centralization has been shown to be a good predictor of overall efficiency of information flow. As such, high network centralization suggests that information is better broadcasted through well connected agents that act as information hubs. Thus, with faster information distribution the system should converge faster. Accordingly, the ACM should converge faster if the network centralization is increased.

*Hypothesis 1b: The centralization of the network will have a negative impact on the time of convergence of the systems.*

Network density describes a network as a ratio of actual ties within the system over the maximum potential connections in the systems. Wassermann & Faust (1999, p. 182) argue that density by itself does not sufficiently describe the centralization of a network, but that it can provide useful information about the network structures as long as it is used in conjunction with the aforementioned centralization measures. A density of 1 indicates that each actor has a direct tie to each other actor within the system. Increasing the network density should have a similar effect then increasing network centralization by increasing the average potential the information flow and thus forcing the system to converge faster.

*Hypothesis 1c: The density of the network will have a negative impact on the time of convergence of the systems.*

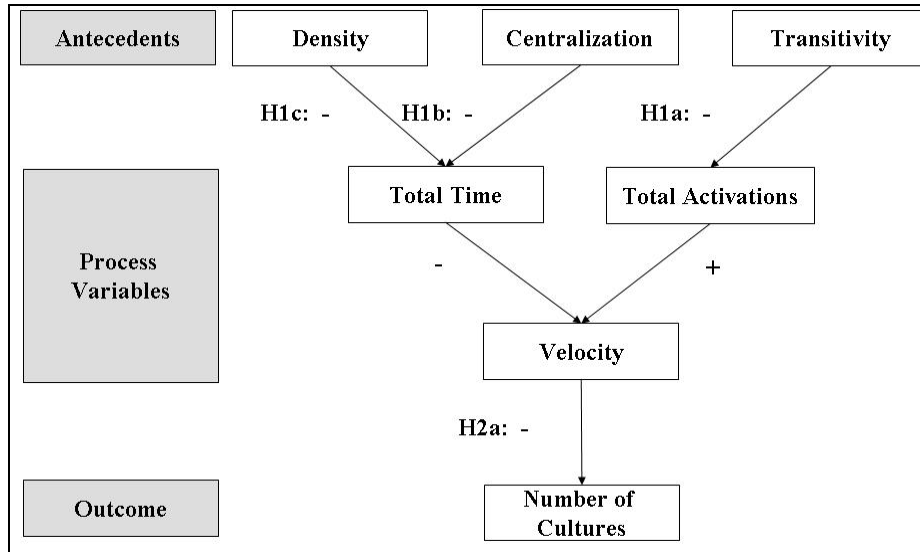
The first set of hypothesis is distinct from previous research by relating the measures of the network structure to the process variables of the simulation: time to conversion and activations until convergence. In the next section I will develop hypothesis that relate process measures to the final outcomes of the simulation.

### *The Impact of Process Measures on the Distribution of Cultures*

In the previous research studies (Axelrod 1997, Greig 2002) the network density was increased by extending the range of interaction, which led to fewer distinct cultures in the converged systems. However, I argue that this was only an indirect result. As discussed before, network measures influence process variables. Laguna et al. (2003) used a process parameter to model the rate of exchange between agents to predict final outcomes. In the context of this network analysis convergence velocity is the ratio of total number of agent activations over time of convergence. I propose convergence velocity as predictor of the distribution of cultures. In particular I argue that higher velocity will lead to fewer distinct culture.

*Hypothesis 2a: The velocity of convergence will have a negative impact on the number of distinct cultures in the converged state.*

The research model is depicted in figure 1. In order to investigate this research model, I adjusted the ACM by removing the geographic neighborhood constraint and introducing a network structure that along with the original similarity constraint governs the exchange of cultural features.



**Figure 1: Research model**

## The Experiment

I programmed two simulations. First I replicated the ACM to validate the simulation. The simulation of the extension followed the original model with the exception that rather than being connected by geographic proximity, agents are part of an imposed network structure. The structure is generated using a fixed coefficient (.0404) for the network density and is operationalized in a 100x100 sociomatrix with 1 signaling a bidirectional tie and 0 signaling a lack thereof. As with the ACM, the exchange of traits occurs when at least one trait is the same. However, the second condition for an interaction is tie as defined by the network structure. A directional tie has to exist in order to fulfill this second condition.

Overall, 100 runs with different initial network structures and traits are carried out. For all activation cycles the changes in traits and number of cultures as well as the relevant network and process measures are recorded. The replication of the original ACM yielded similar results, with the median of final cultures (3), and the percentage of heterogeneous systems with more than six cultures (10%) being equal and the number of systems with homogenous cultures being slightly higher (14% vs. 16%).

The extension removed the spatial network structure. Bidirectional ties were randomly assigned (seed of 400 ties) over 100 runs, thus producing variations in density, transitivity and centralizations for each run. Table 1 shows the means of the variables of both the base experiment and the extension experiment. Two OLS and one Poisson regressions were undertaken to test the respective sets of hypotheses. The regression results are depicted in Table 2.

**Table 1: Means of variables**

	Transitivity	Centralization	Density	Activations	Time	Velocity	# of Cultures
Base	0	0	0.040	12562	572	22.5	3.63
Extension	0.0415	0.594	0.041	9740	388	25.6	4.17

The results of the regression show that all hypotheses are supported and that the network antecedents only indirectly influence the final outcome of the simulation. The antecedents influence convergence velocity, which in turn influences the number of final cultures. Transitivity has a negative effect on total activations, which translates into a negative effect on

velocity. Thus, more clustered networks exchange less information in total which leads to local convergence but to global divergence, resulting in a higher number of final cultures. Network centralization negatively effects time to convergence, thus increasing the velocity of convergence. As such if a number of cultures are better connected than the remaining cultures, they act as information bridges; leading to faster convergence and fewer final cultures. Lastly, a higher network density which can be interpreted as a higher average of connections by each cultures has the same effect as centralization, given that each agent has a higher capability of acting as an information hub.

**Table 2: Regression Results**

	Time	Activations	Cultures (Poisson)
Intercept	<b>746.7 (136.5)***</b>	<b>13452.3 (4420.7)**</b>	<b>3.24 (0.73)***</b>
Transitivity	204.2 (0.248)	<b>-44785.9 (26671.4)**</b>	-3.47 (4.52)
Centralization	<b>-2272.2 (816.1)**</b>	-31343.2 (26435.1)	2.31 (4.36)
Density	<b>-5673.7 (3288.4) .</b>	260.5 (106513.2)	-12.63 (17.88)
Velocity	N/A	N/A	<b>-0.053 (0.007)***</b>
Adjusted R <sup>2</sup>	0.085	0.021	N/A
Significance Levels: '***' 0.001, '**' 0.01, '*' 0.05, '.' 0.1			

The network structure of the original ACM does not allow for the influences of transitivity and centralization since both are 0. Only network density indirectly influences the number of final cultures. This explains why the results of previous research (Axelrod 1997, Greig 2002) where an increase in range, which essentially is an increase of the average connections equally across cultures, will lead to a decline in final cultures. This result is conditioned upon the fact that all agents enjoy an equal increase in ties, where the network simply consists of more weak ties rather than of potential clusters with strong ties. If the latter were achieved, we might see final outcomes where the effect of higher density may be offset by the effect of transitivity.

## Conclusion

Overall this research shows that the spatial lattice structure of the original ACM is an extreme case in terms of network structure. While it explains the spread of culture in small geographical settings, it cannot necessarily be generalized to any network setting. This research was presented a first attempt to test the robustness of the ACM in parameterized network settings. While the overall outcome of system convergence still holds true, it has to be noted that the size of the outcomes is affected by introduced antecedents.

Yet, the extension still includes abstractions from real world network setting. First, the bidirectionality of the tie between different cultures need s to be addressed. Similar to Shibanaï et al. (2001), I argue that different cultures might be doors of cultural traits while others might be receivers. An equal relationship between to agents seems highly unlikely. In a similar vein, Rogers (2003) argued that there are opinion leaders and change agents that might have a larger influence upon others or strictly follow an agenda favoring cultural string over another. Moreover, the limits of the network structure need to be tested. In preliminary studies I encountered systems with low network densities that would not converge. Assuming that real world networks are rather sparse, it might be useful to test what the minimum requirements for a convergence of the ACM are. Further, I would note that both the ACM and my extension assume a static network structure. However it seems more realistic that ties change over time and that that individuals might develop their own cultural traits without the external influence. In that regard it is also important to note that ties themselves are not necessarily dichotomous in nature. Rather there should be a probability attached to the strength of the tie that regulated the occurrences of interaction.

Further, I want to point out that it is important to focus in on the process variables of simulation. Given the complexity of social network simulation, there needs to be a better understanding of the processes leading to a specific outcome. This research is an attempt to both shed light on the network antecedents and the process that lead to the outcome of the ACM. Yet, the objective of the research has to be find generalizations of complex systems that are looking beyond the application of a single model.

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