TechNet_04:
A Simple Model of Cultural Transmission in a Spatially-Situated Network

The TechNet_04 model is one of a series of abstract models that was developed to begin examining the basic relationships between the structure of prehistoric social networks and patterns of variability in material culture. It was constructed to be a simple, flexible platform for running an array of experiments to investigate relationships between network structure, network properties, artifact variability, and the spatial organization of artifact variability.

The code (in Java) for the main files of the TechNet_04 model is supplied in the code section as a text file. This file contains the code for three files: Model.java, Group.java, and Link.java.

Table 1 supplies a description of the main parameters and variables of the model.

Spatial environment and population

The "world" of the model is a two-dimensional, bounded, hexagonal grid. Each cell is the location of a single "group". A hexagonal grid was chosen because it equalizes the spatial distances of the neighbors of any particular cell at a given number of tiers. A bounded grid was used instead of a torus because the model is intended to represent a social world that has spatial limits.

A population of groups is created and placed in the world during the set-up phase of the model. Because each cell contains a single group, the number of cells and the population of the world are identical: a 40 x 40 world contains 1600 groups. Each of these groups has an "address" consisting of X and Y coordinates that specify its location in the grid. Each group also has a set of A and B hexagonal grid coordinates that are used to determine spatial distances between groups in terms of the number of cells (Figs. 1.A and 1.B).

Network structure and properties

This model is built around the concept that each group can interact with a unique, finite array of other groups to which it is linked. This array constitutes a group's individual network. When two groups are linked, information can be transferred between them. The overlapping networks of individual groups comprise a system-level network that connects all groups within the system.

Networks are formed at the beginning of a model run and are static (i.e., they do not change during a model run). Networks are formed through a two-stage process. In the initial stage, each group adds its local neighbors (i.e., groups in the immediately adjacent tier of hexagonal cells) to its *networkList,* a list for storing the identities of other groups in its network. An agent located somewhere in the middle of the grid would add the six agents in the neighboring grid cells to its *networkList* (Fig. 1.C). This produces a "local only" network where each group is linked to only those groups who are immediately adjacent to it in space.

Table 1. Main parameters and variables of TechNet_04 model.

Level	Parameter/Variable	Description
Group	*id*	Unique identifier for each group
	X, Y	Group's XY coordinates; used by the model to identify locations within the grid
	A, B	Group's AB coordinates; used to calculate geographic distances between cells
	networkList	List of all groups to which a particular group is linked
	variableA	Group's current value of *variableA*
Link	*fromGroup, toGroup*	Groups connected by the link
	linkDistance	Geographic distance spanned by the link
System	*meanNetworkSize*	Mean size of all group-level networks in the system
	numLinks	Total number of links in the system-level network
	linkDistMean	Mean geographic distance spanned by links in the system
	longestLink	Longest geographic distance spanned by a link
	meanPathLength (MPL)	Mean path length of system-level network
	clusteringCoefficient (CC)	Clustering coefficient of the system-level network
	meanSD	Mean standard deviation of *variableA*, averaged over 500 time steps
Model	*p*	Parameter setting probability of replacement of local links with random links (in *rewireMode* 1) or addition of non-local links (in *rewireMode* 2)
	rewireMode	Parameter determining process for rewiring the local-only network that is established at the start of a model run
	rewireRadius	Radius (in tiers of hexagonal cells) within which links to non-local groups can be added when *rewireMode* = 2
	pConform	Parameter setting probability that a group will copy some other population of groups (determined by *copyMode*)
	copyMode	Parameter controlling the population a group will copy: 1 = group copies mean *variableA* of groups on its *networkList;* 2 = group copies mean *variableA* of entire population; 3 = group copies its own *variableA*; 4 = group copies median *variableA* of entire population; 5 = group copies deterministic mean that changes according to formula
	copyError	Percentage +/- error applied when copying

A second stage of network formation "rewires" this local-only network in one of two ways, controlled by the parameter *rewireMode*. If the value of *rewireMode* is 1, a group's local links to its neighbors can be replaced by links to random groups (Fig. 1.D). The probability of each local link being replaced by a random connection is controlled by the variable *p*, which is a parameter that can be set between 0 and 1. Each group goes through its *networkList* and puts each member of its network in jeopardy of being replaced by generating a uniformly distributed random number between 0 and 1 and comparing it to the value of *p* set in the model. If the generated number is lower

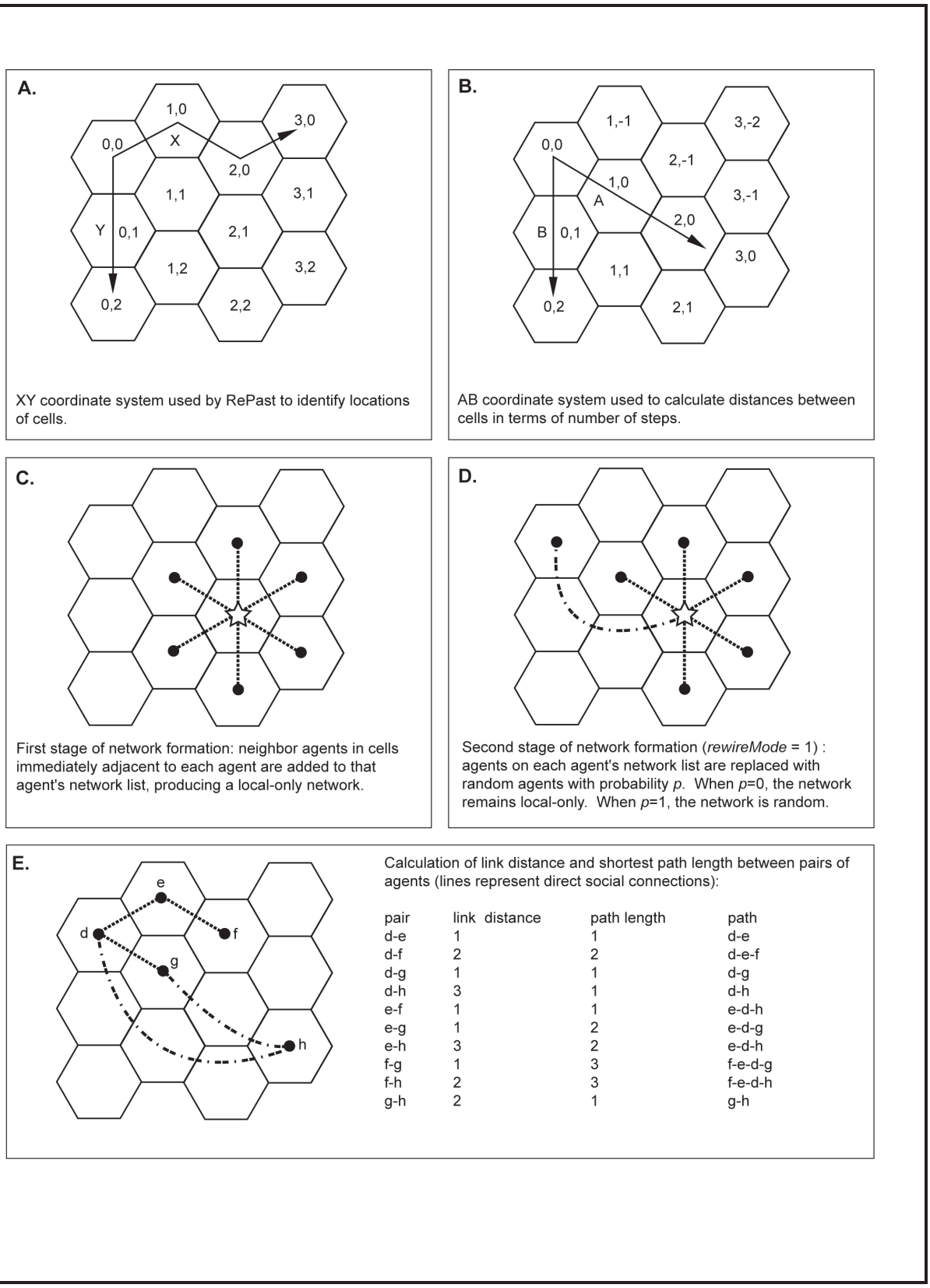


Figure 1. Conceptual illustration of coordinate systems, stages of network formation, and calculation of link distance and path length in the TechNet_04 model.

than *p*, the link with that group is dissolved and a new link is formed with a randomly selected group. Thus when *p* = 0 (no chance of replacement) the network remains local-only, while a *p* of 1 (certainty of replacement) produces a network where each link is randomly determined. Because each link between two groups is two-way, each connection can be in jeopardy of being replaced twice. This procedure of network "rewiring" to interpolate between a regular and a random network is similar to that employed in studies exploring the small-world property (e.g., Klemm et al. 2003; Watts and Strogatz 1998). The main difference is that, in those papers, each link between vertices was only subject to potential rewiring once.

The bounded nature of the grid and the spatial component of network formation mean that groups located along the edges of the grid have fewer than six other groups in their networks. In a 40 x 40 grid, the mean size of a group's network (*meanNetworkSize*) is 5.8 and there are 4641 direct two-way links between groups. The rewiring of the network controlled by *p* does not affect the total number of direct links in the network: for each link that is dissolved a new one is created. Thus *meanNetworkSize* remains constant in *rewireMode* 1. Rewiring in *rewireMode* 1 does affect the distribution of links among the groups in the network, however. When a local group is replaced with a random group, the local group loses a link while the random group gains one. Because of this, it is possible for individual groups to become disconnected from the rest of the population. Groups that become unlinked during rewiring are removed from the world prior to the start of a model run.

If the value of *rewireMode* is 2, each group has the chance to create links with non-local groups that are within a specified distance of the group's location. In this mode, a group preserves links with all of its local neighbors and adds links to other, non-local groups. The probability that a group will create a link with a non-local group is, again, controlled by the parameter *p*. The number of chances each group has to add non-local links was held constant at 6 (the mean size of a local-only group-level network, rounded up from 5.8). In other words, when *p* = 1, each group will add links to 6 nonlocal groups. The geographic distance between linked groups is constrained by the parameter *rewireRadius*, which specifies the maximum separation of two linked groups in terms of the number of hexagonal cells. If the value of *rewireRadius* is 8, for example, a group will form a link with a randomly selected group that is between 2 and 8 tiers distant (it is already linked to all the groups within 1 tier). Because links are added rather than replaced, the mean network size will vary but will always be greater than 5.8 when p > 0.00. If a group tries to create a link to a group with which is already linked, that chance to add a link is lost.

After the network is formed, the model computes the mean path length (*meanPathLength*, or *MPL*) of the network. *MPL* describes the average social distance from one group to another group in terms of the shortest number of social "steps" between the groups (Fig. 1.E). When a group is directly linked to another group, the length of the path between them is 1. When a single intermediary is required to reach one group from another group, the path length between them is 2. The model computes the sum of the path lengths between each unique pair of groups and then divides the total path length by the number of paths. There are 1,279,200 group-group paths in a grid of 1600 groups. The *meanPathLength* of a 40 x 40 grid with a local-only network is

21.5.

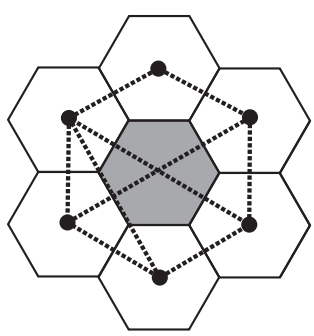
The variable *linkDistance* describes the geographical distance traversed by a link terms of the number of spatial steps (Fig. 1.E). The variable *longestLink* describes the geographic distance traversed by the longest group-group link that exists in the grid. The value of *longestLink* in a local-only grid will always be 1. When non-local connections are possible, the distance of the longest possible link will be limited by the size of the world in *rewireMode* 1 and by the value of *rewireRadius* in *rewireMode* 2. The variable *linkDistMean* is the mean distance of all group-to-group links.

The model also computes the clustering coefficient (*clusteringCoefficient*, or *CC*), which measures the mean inter-connectedness of local neighborhoods (see Watts and Strogatz 1998). The clustering coefficient of each local neighborhood (i.e., the area occupied by a group and the immediately adjacent groups) is defined as the ratio of the number of links that exist among a group's local neighbors to the number of links that are possible among those neighbors (Fig. 2). When a group has six neighbors, a total of 15 links are possible among them. If 11 of those links exist, the clustering coefficient in that neighborhood is 0.73. The *clusteringCoefficient* of the system-level network is the mean of the clustering coefficient of all neighborhoods. The *CC* of a 40 x 40 grid with a local-only network is 0.4122.

Information transfer

The transmission of cultural information in this model is represented by the transfer of the value of a single real number (*variableA*). *VariableA* is meant to represent some continuously variable, "stylistic" aspect of artifact size, shape, etc., that is subject

The clustering coefficient is defined (following Watts and Strogatz 1998) as L_A/L_P, where L_P is the possible number of links that could exist among a group of *n* neighbors and L_A is the number of links that actually exist.



The central group above has six neighbors. The number of possible links among these six groups is 15: (n*(n-1)/2). When 9 links exist (as shown above) the clustering coefficient is 0.6 (9/15).

Figure 2. Calculation of clustering coefficient in the TechNet_04 model.

to copying error and is free to vary through processes such as drift. Because the purpose of this model is to understand only the relationships between the structure and properties of social networks and the amount and spatial organization of the variability that is produced through simple copying error, no attempt is made to represent functional constraints on variability (i.e., there is no selection that constrains change) or "emblematic" aspects of style (where style is consciously recognized or employed as a marker of group identity). When used without qualification in this paper, the word "variability" refers to "passive" stylistic variability.

Every group in the world begins a model run with the same value (5) of *variableA*. This was an arbitrary value selected so the results of some experiments would be directly comparable to those of previous work (e.g., Hamilton and Buchanan 2009). Because variability generated during a run is proportional to the value of *variableA*, beginning with a different value would affect the results in terms of absolute values but not the overall patterns.

The transfer of information occurs through copying events. At each time step, each group copies the value of *variableA* either from itself or from some population of groups other than itself (see Table 1). Two variables control these choices: *pConform* specifies the probability that a group will copy some "pool" of groups other than itself, while *copyMode* controls which pool that is. In other words, the variable *pConform* controls the relative strength of "horizontal" vs. "vertical" transmission, while *copyMode* determines the population that is copied if a group copies an outside population.

The variable *pConform* can be set between 0 and 1. This variable is conceptually the same as the variable lambda (or "strength of bias") used by Hamilton and Buchanan (2009) and "strength of conformance" used by Eerkens and Lipo (2005). When *pConform* equals 0.30, an agent will copy the value of *variableA* from a population of groups other than itself with a probability of 0.30. If the group does not copy from an outside population (i.e., does not undertake "horizontal transmission"), it will copy itself by default ("vertical transmission").

In the event that a group copies the value of *variableA* from an outside population, the mode of copying (*copyMode*) determines the composition of that population: the mean *variableA* of the groups in its network or the mean (or median) *variableA* of the entire population in the world. The latter mode of copying does not incorporate any aspects of network-structured interaction (as the group is simply copying some global measure of the central tendency of the population), but allows the model to be used to reproduce the results of equation-based cultural transmission models that do not represent interaction as a structured phenomenon.

Variability in *variableA* is generated through copying error (controlled by the parameter *copyError*) that is applied each time a group copies (whether copying from an outside population or copying itself). The application of error during each copying event is based on the idea that there are inherent constraints in human perception that prevent the detection of slight differences between any two objects, shapes, colors, etc. The amount of error is relative and is typically set at a maximum of +/- 3 to 5 percent based on empirical studies of human perception (e.g., Eerkens 2000; Eerkens and Lipo 2005; Hamilton and Buchanan 2009). This model allows copying error to be either uniformly or normally distributed (Fig. 3). When copying error of +/- 5 percent

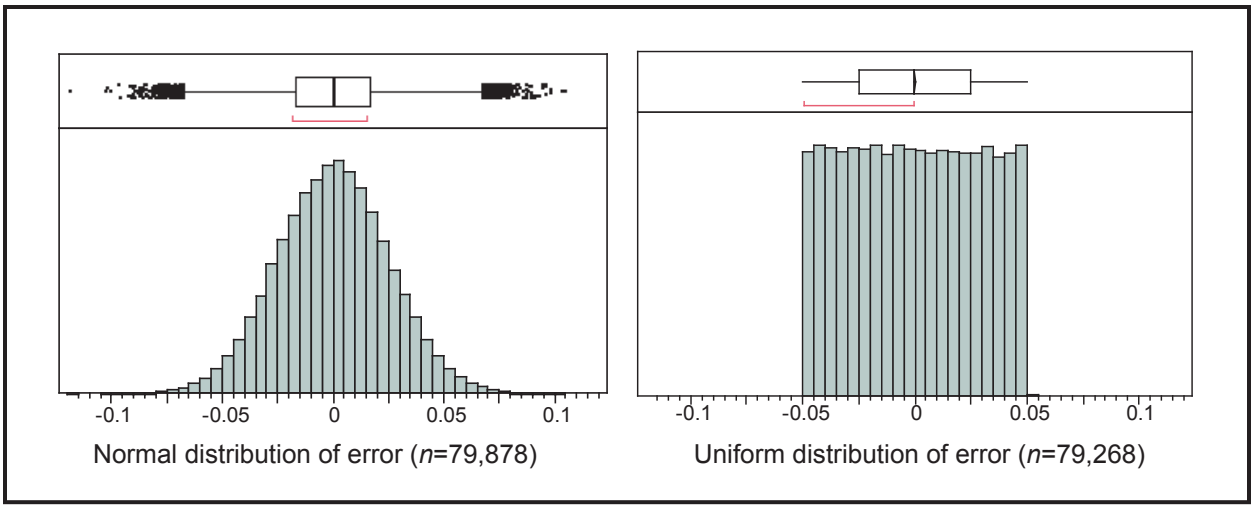


Figure 3. Histograms showing normal and uniform distributions of +/- 5 percent error.

is normally distributed, the mean error is 0 and the 5 percent error is two standard deviations from the mean (errors greater than 5 percent can occur when the error is normally distributed). A uniform distribution of error places a hard limit on the amount of error that can occur. The experiments performed here used a normal distribution of error simply to follow the standard practice in mathematical studies of cultural transmission.

Model operation

Following creation of the world and the groups, two-stage formation of group-level networks, and setting of parameters controlling information transfer, the model is set into motion. At each time step, each group goes through a sequence of actions during its turn. It first determines whether it will copy *variableA* from itself or from some outside population (based on *pConform*). If it copies from an outside population, it determines the population to copy (based on *copyMode*), calculates the value of *variableA* to copy, applies copying error, and copies. If it copies itself, it applies copying error to its own value of *variableA*. The ordering of groups is randomly shuffled each time step. Most of the runs discussed here lasted for 1000 time steps.

The data output of the model can be adjusted to include different measures and more or less detailed data depending on what is required for analysis. Outputs can range from summary data produced at the end of a run to data about each group at each step.

Bibiolographic References

Eerkens, J.W., 2000. Practice makes within 5% of perfect: visual perception, motor skills, and memory in artifact variation. *Current Anthropology* 41, 663-667.

Eerkens, J.W., Lipo, C.P., 2005. Cultural transmission, copying errors, and the generation of variation in material culture and the archaeological record. *Journal of Anthropological Archaeology* 24, 316-324.

Hamilton, M.J., Buchanan, B., 2009. The accumulation of stochastic copying errors causes drift in culturally transmitted technologies: quantifying Clovis evolutionary dynamics. *Journal of Anthropological Archaeology* 28, 55-69.

Klemm, K., Eguíluz, V.M., Toral, R., Miguel, M.S., 2003. Nonequilibrium transitions in complex networks: a model of social interaction. *Physical Review E* 67 026120, 1-6.

Watts, D.J., Strogatz, S.H., 1998. Collective dynamics of “small-world” networks. *Nature* 393, 440-442.