Modeling the Spread of Ideas in Networked Environments

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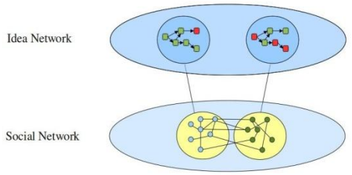
INTRODUCTION

Extant models of information transmission demonstrate how structural factors, such as the structure of a social network, impacts the propagation of ideas. We take a somewhat different approach and argue that the spread of ideas through a social system depends largely on psychological factors (e.g. the beliefs, attitudes and values shared by groups of individuals).

A particular focus of interest for us concerns what are known as 'idea models', which correspond to models of culturally-entrenched belief systems. One way of representing such models is as a network of causally-linked concepts, where the nodes represent specific concepts and the links represent specific cause-and-effect relationships. The result is what we refer to as an 'idea network'. The figure below illustrates the idea networks of two groups (upper ellipse) composed of individuals who interact via a social network (lower ellipse).



Existing Models of Idea Spread

We will now review a few areas of the literature relevant to the study of idea spread. These areas provide some insight into how the characteristics and functions of ideas might influence their spread in a social system.

Diffusion of innovations

Diffusion of innovation researchers, such as Everett Rogers (Rogers, 1995), have proposed conceptual models of idea spread that take into account decision-making, attitudes, and the similarity of social actors. A popular computational model arising from Roger's work is the Bass Diffusion Model (Bass, 1969), which takes the following form:

$$\frac{f(t)}{1 - F(t)} = p + \frac{q}{M}[A(t)]$$

This model shows that the rate of adoption of an idea depends on the prevalence of the idea in the population, as well as factors such as the intrinsic value of the idea and the quality of its advertisement. Once these factors are specified, the function can be used to predict the number of people who will adopt the idea over a given period of time.

The Bass Diffusion Model provides some insight into the mechanisms of idea spread; however, it focuses primarily on the outcome of the idea propagation process (e.g. it predicts the number of people who adopt an idea) rather than the details of the actual process itself. This means that the model is not particularly well-suited to the development of computational models that attempt to simulate the process of idea propagation.

Memetics

Richard Dawkins coined the term 'meme' to reflect the putative similarity between genetic transmission and idea transmission. The main objective behind the concept of the meme was to identify a discrete unit that could be transmitted by way of a 'replicator', similar to the way in which genes themselves are transmitted from one generation to the next. Dawkins work underpinned the formation of the memetics movement, which produced several genetically-inspired computational models of idea spread.

Perhaps the most influential memetics model is the one proposed by Cavalli-Sforza and Feldman (1981). This model describes both the inter- and intra-generational transmission of ideas, and it incorporates several genetically-inspired factors. The fitness of an idea is defined in terms of a selection function, and the model also incorporates mutational mechanisms.

One of the primary contributions of memetics is the notion that the spread of an idea is largely determined by the characteristics of the idea itself. Lynch (1996), for example, describes *self-propagating* ideas as ideas with features that promote their own propagation (e.g., the proselytizing message found in many religious doctrines). However, memetic-based models often fail to account for the importance of the beliefs shared by *groups* of people.

Cultural Transmission

Recently, simulation-based models have emerged that demonstrate how simple interaction rules and feature-based representations can drive the development of multiple cultures with differing sets of ideas. Robert Axelrod is seen as the pioneer in this area. His multi-agent simulations (e.g., Axelrod, 1997) define simple interaction rules (see below) that promote idea consensus. However, when the parameters are set correctly, the simulations can give rise to distinct communities of agents, each possessing different sets of ideas.

Axelrod 's simulation algorithm:

1. Select a unit at random and then choose one of its neighbors, again at random.
2. Determine the feature similarity of the units (this is essentially the proportion of features in the unit's and neighbor's idea sets that are the same).
3. If the units interact, then select one of the features of the neighbouring unit (at random) and assign it to the currently selected unit.

A limitation of Axelrod's model is that beliefs are represented as sets of unrelated features. Research has shown that culturally-shared beliefs are much more complex. Furthermore, Axelrod's simulations are initialized with random configurations. In reality, interacting agents are already part of one or other cultural group, even though there is some variability between the agents in terms of their individual beliefs.

Random initial configuration

Result of the simulation. Three distinct cultures have emerged (indicated by the black, purple, and orange regions)

OUR APPROACH

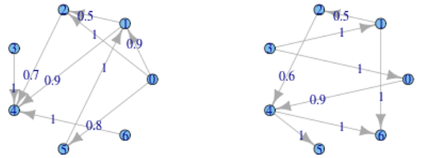
The current study adopts a simulation approach similar to Axelrod's, and it attempts to demonstrate how idea networks can drive idea spread. There are three distinct features of our simulation:

1. Our idea representation is based on the notion of an idea network. Previous simulations have used sets of independent features for an agent's ideas; however idea networks feature complex interdependencies between ideas.
2. Our agents are not randomly initialized. The initial idea networks are spawned from cultural models that represent a culture's specific set of ideas (see below).
3. Our simulation contains no social network constraints. We are interested in studying the effects of the constraints at the level of idea networks. Therefore, any agent can talk to any other agent during the course of the simulation.

Idea Representation

Over the last couple of years, we have developed an end-to-end framework for modeling culture, which is known as *Cultural Network Analysis* (CNA) (see Sieck and Rasmussen, 2008). Idea networks are one outcome of the CNA process, and they may be thought of as mental models that are distributed across individuals in a particular cultural group. In the figure below, the weights associated with the links represent the proportion of people in the cultural group who have a particular idea.

Cultural Models in Simulation



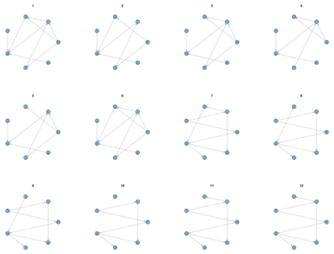
Simulation

To test the simulation, we initialized 12 agents with binary idea networks (they either had each idea/link or they did not). Six agents were spawned from cultural model 1 and 6 from cultural model 2 (see figure above). The initial configurations are shown in the figure below. The spawning process is based on the numbers associated with the links in the cultural model. So, for a proportion of 0.5, a single agent has a 50/50 chance of having the idea/link when spawned.

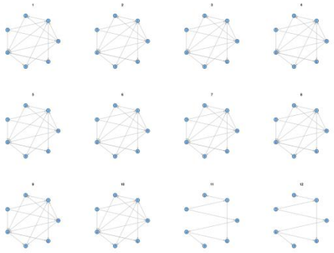
The simulation was run for 3000 iterations. For each iteration, two agents were chosen at random to interact. Of the two selected agents, a connection was chosen from one agent's network (a connection could be a single link, or a path through several links). The connection was then tested against the second agent's network. If the second agent had the exact connection, or could infer the same causal relationship (e.g., agent 1 has a link from A to B and B to C, while Agent 2 has a single link from A to C), the second agent either adopted a link from the first agent or lost a link he had but agent 1 did not.

RESULTS

Initialization



Results



DISCUSSION

The results show how the initial idea network drives the transmission of ideas. Similar to Axelrod's observation, agents that were initialized based on a slightly more diverse model were more likely to adopt other agents' beliefs. This led to the development of many hybrid networks. However, two of the agents whose idea networks were spawned from cultural model 2 were not able to "break out of their initial belief set" and stayed true to their original idea network. The variability inherent in the cultural models certainly contributed to these within-culture effects.

Modelling the spread of ideas in the form of interacting causal belief models is advantageous because it allows us to better characterize the actual process of idea propagation in social systems. Social network characteristics are important when modelling the spread of ideas; however, cognitive considerations are also important in understanding the mechanisms underpinning idea propagation (see Simpkins et al, in press). Idea networks provide an interesting means of representing at least some of the cognitive factors that contribute to the dynamics of idea propagation in real-world social systems.