Idea Propagation in Social Networks: The Role of 'Cognitive Advantage'

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Introduction

Existing models of information transmission emphasize the role that structural factors play in the network-mediated spread of ideas[1]. For example, the density of a communication network may be emphasized as a critical factor in determining the rate at which an idea spreads throughout a particular community. While such structural factors are no doubt important, it is also important to consider the role of psychological and cognitive factors in shaping the profile of idea propagation. A consideration of the psycho-cognitive context in which idea transmission takes place may serve to enhance the explanatory and predictive accuracy of existing models[2], and it may also contribute to improvements in their ecological validity.

The central thesis of this paper is that pre-existing, culturally-entrenched beliefs, concepts and values (which we collectively refer to as 'ideas') play an important role in the dynamics of idea propagation. They do this by determining the relative 'cognitive advantage' of particular ideas. The cognitive advantage of an idea is, in broad terms, the acceptability of an idea to a particular (culturally-circumscribed) community. It determines the tendency of ideas to become established in a community, as well as the rate at which those ideas are transmitted from one individual to another.

Understanding the cognitive advantage of a new idea requires a detailed understanding of the pre-existing beliefs and values that are held by a particular community. For just as the success of a new species in a particular ecological niche is determined by an existing nexus of inter-species relationships, so the acceptability of a new idea is determined by an existing nexus of beliefs and values that characterize (and indeed define) culturally-circumscribed communities. In order to better understand the cognitive advantage of new ideas, we must therefore develop a better understanding of the 'cognitive niche' into which new ideas are to be introduced. Cultural Network Analysis (CNA) (Sieck, 2010; Sieck & Rasmussen, 2007; Sieck et al., 2010) is a technique that enables us to analyze and represent the idea networks of specific cultural groups, and it therefore provides one means by which the cognitive advantage of new ideas can be assessed. When combined with conventional approaches to modelling information flow and influence in social networks, the notion of cognitive advantage allows us to better account for the specific profile of idea propagation within

[1] The term 'idea' in this paper is used as a catch-all term for concepts, beliefs, and values.

[2] In particular, a focus on the pre-existing beliefs of particular communities may enable us to better understand and account for the differential rate of spread of ideas within those communities. In addition, once we come to understand the belief systems of cultural groups, we may be in a better position to deliberately influence the rate of idea propagation within those groups (e.g. by presenting those ideas in ways that align themselves with pre-existing beliefs and values).

target communities. It essentially provides an important step towards the development of more ecologically-realistic models of group-level cognitive dynamics.

The aim of the current paper is to review the literature on idea propagation in social networks, and to introduce the notion of cognitive advantage. Since the literature on idea propagation is large and somewhat unwieldy, our review will be necessarily limited. In fact, we focus on three types of models that have been developed to account for idea propagation. These include diffusion of innovations models, cultural transmission models and memetics model. Later in the paper, we present the technique of CNA and show how it can be used to develop a better understanding of the psycho-cognitive context in which idea propagation takes place. Before that, however, we begin with a discussion of the likely effect of network structure on the dynamics of idea propagation in military coalition operations. This example is taken from our recent work in the International Technology Alliance[3] (ITA) research programme, which is a consortium of academic, industrial and government partners seeking to undertake fundamental research in the information and network sciences.

Network Structure and Cognitive Syncretization: A Multi-Level Network Approach to Idea Convergence in Military Coalitions

Military coalitions are complex organizations involving individuals from multiple nation states and military services (i.e. air force, navy and army). Cultural differences exist between the members of a coalition (e.g. Rasmussen et al., 2009), and this may present problems for communication, cooperation and the development of trust between coalition partners. Since one approach to revealing cultural differences is to investigate the casual beliefs associated with some decision outcome (e.g. what beliefs are associated with the positive evaluation of a military plan), it often makes sense to represent the cultural differences between coalition partners in terms of (what we refer to in this paper as) idea networks (i.e. networks of causal beliefs and value judgements). A key focus of previous work in military coalition contexts has been to develop idea networks in order to identify the potential barriers to effective forms of communication and collaboration between coalition partners. In the context of this paper, however, it is worth thinking of such networks in a slightly different way. In particular, we can ask how the structure and content of idea networks changes in response to the dynamics of information flow and influence in a variety of coalition communication networks[4], such as the physical communication network (the communication links that are established between specific communication devices) and the social communication network (the communication links that are established between specific agents). Given that these

[3] http://www.usukita.org/

[4] Military coalitions have been described in terms of multiple interconnected networks (i.e. 'networks of networks') that subtend the human, technological and informational domains. The relationships between human agents, for example, may be seen as forming one kind of network (e.g. a social network), while the relationships between elements of the physical communication infrastructure may be seen as forming a different kind of network (i.e. a physical communication network). By conceptualizing coalition organizations as 'networks of networks', we draw attention to two things. The first is that there is a subtle yet important inter-dependence between the various elements of the coalition environment. For example, the physical and social communication networks may be expected to interact in complex, non-linear ways throughout the course of coalition operations, and the challenge, in this case, is often to coordinate the structure and activity of these networks in ways that enhance the collective performance of the larger coalition organization. A second reason why the notion of 'networks of networks' is important is because it underscores the importance of network scientific approaches to representing, analysing and understanding military coalition environments. Such approaches are evidenced by recent works in the information and network sciences (Verma, 2010).

communication networks determine the opportunities for inter-agent communication (as well as the nature of the communication that takes place), we might expect that the structures of both physical and social communication networks would play a key role in determining the evolution of idea networks in response to episodes of cross-cultural interaction. For example, if we are talking about the propagation of ideas from one cultural group to another, then it seems likely that the structure of the social communication network between the two groups will influence the rate at which ideas are propagated, as well as the rate at which those ideas are adopted (i.e. incorporated into idea networks)[5].

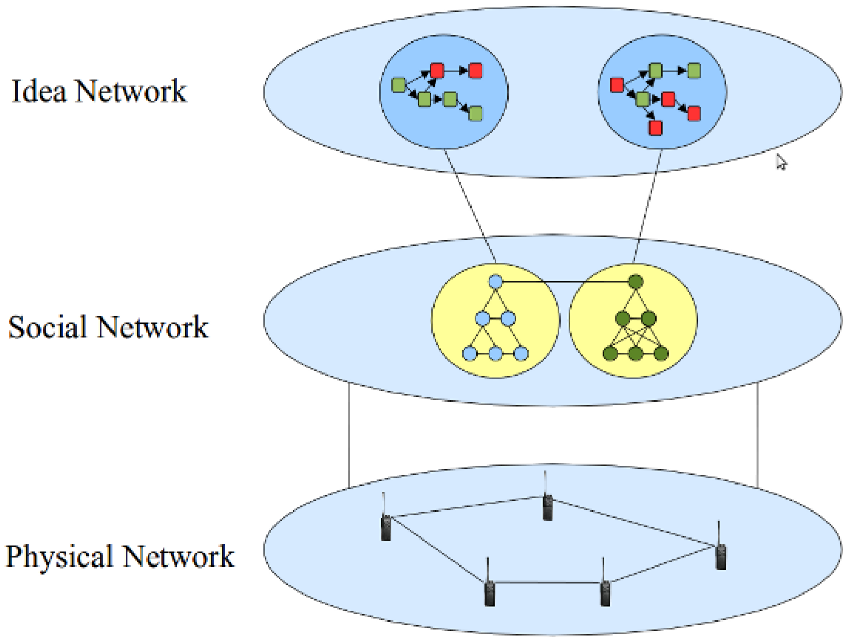

Figure 1: Network layers in a coalition environment. This figure shows the state of the coalition before any interaction between the coalition partners has taken place.

To help make this potential independence between communication and idea networks a bit clearer, consider Figure 1. Figure 1 shows the three kinds of networks that we have just been discussing. The bottom layer is the physical communication network, which consists of the various hardware components used to enable communication between coalition partners. In this layer, the nodes in the figure represent the hardware devices used to transmit and receive information, while the links between the nodes correspond to the physical linkages between hardware devices. The number of communication channels, the quality of the transmission signal, and the distance over which information is to be transmitted are all factors that constrain the transmission of information at this layer. The second layer, which is impacted by the configuration of the physical network layer, is the social network layer. At this layer, nodes represent people (or other intelligent agents), and the links

[5] It is also possible, of course, that as ideas get propagated within a community, the actual structure of the social network itself changes. This may (perhaps) occur in cases where some individuals in a cultural group accept a particular idea, while others in the same cultural group reject it. The result may be a fragmentation of the original social network into smaller constituents. Inasmuch as this sort of process actually takes place, we may begin to think of individual psychological differences between individuals as the fault lines along which social networks fragment following their exposure to new ideas. This kind of view sees new ideas as contributing to seismic shifts in the tectonic organization of culturally-significant social groupings.

between the nodes represent the channels of communication between agents. At the social network layer, we are primarily interested in aspects of inter-agent communication; for example, the frequency of communication between particular agents. The top-most layer, which is impacted by the configuration of both the physical and social network layers, is the layer of idea networks. This layer consists of networks of inter-related ideas (i.e. concepts, beliefs, and values) that are distributed across the individuals in a particular population (e.g. US military service personnel). For this layer, the nodes correspond (broadly) to concepts, and the links correspond to the causally-significant relationships between the concepts. Culturally-shared values, which are associated with concepts, are also represented in the idea networks by (e.g.) colour-coding schemes to indicate positive/negative valence. Figure 1 shows one possible state-of-affairs at the beginning of a military coalition engagement. In this case, there are two distinct idea networks, one for each coalition partner (e.g. one for US forces and one for UK forces), and (at least in this model) there are no linkages between the two idea networks[6].

The current predominant physical transmission layer infrastructure for coalition operations (at least land-based ones) is a two-way radio network system. This system is limited in terms of the number of available communication channels, the quality of the transmission signal, and the distance over which the radios can be used. Networked systems of computers are currently used by both the US and UK armed forces, but the predominant means of communication during actual operations is through radios. The anticipation of both the US and UK armed forces is that networked computer systems will largely replace these radios in the future. There is a particular interest here in the power and flexibility of mobile ad-hoc networks (MANETs). Simply put, a MANET is a self-configuring computer network containing properties that allow network nodes to be completely inter-operable[7]. If this system is implemented at the physical network layer, it is anticipated that there will be a significant effect on both the social and idea network layers (see Figure 2). For the social network layer, the hierarchical structure that is ubiquitous in many military systems will be replaced by a system in which individual nodes are connected by fewer and fewer intermediate links. Theoretically, anyone will be able to initiate communication with anyone else via direct communication links, and, as a result, the rate of information transmission across the entire coalition will be increased. It is generally assumed that the shorter distance between nodes in the physical communication network (and the resulting capability for direct contact at the social network layer) will facilitate the sharing of information between coalition partners, and one possible outcome of this state-of-affairs is that a single network of ideas will emerge that is widely shared among all coalition members (see Figure 2). What we may see, therefore, following the introduction of new

[6] As in many empirical network models, different idea networks do not have to be exclusive; two or more idea networks can share common elements (i.e. concepts, beliefs and values).

[7] This emphasis on inter-operability at the level of the physical communication network parallels, to some extent, the emphasis on inter-operability at the level of idea networks. The general idea is that differences between idea networks are just as much the potential barriers to effective communication as are the technological incompatibilities between different network devices (e.g. devices using different networking protocols). The solution in the case of the physical communication layer is to develop smarter, more compatible and self-configuring networking solutions. The solution in the case of culturally-distinct idea networks, however, is somewhat less clear cut. Ideally, what is required is some way of making coalition partners more aware of the cultural differences that exist between them and more capable of adaptively configuring themselves so as to optimize communication in different collaborative contexts. Perhaps analogues of some of the solutions discovered for military coalition MANETS can be developed within the human sciences in order to facilitate communication and collaboration between coalition partners.

types of coalition communication network infrastructure is a greater rate of convergence in the idea networks associated with culturally-distinct coalition partners. Inasmuch as such convergence obviates, or at least attenuates, the difficulties associated with communication, interoperability, trust and collaboration between coalition partners, then the introduction of new, more efficient communication networks seems to have much to commend it[8].

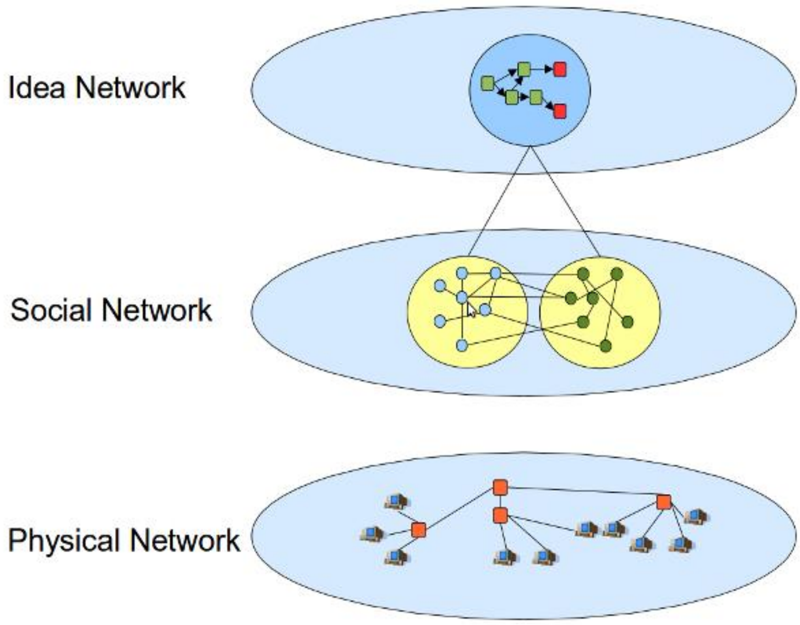

Figure 2: Network layers in a coalition environment. This is the state of the three networks after the coalition has been in operation for some time. As is shown in the figure, a single hybrid idea network has developed based on the interactions made possible by the structure of both the physical and social communication networks.

The general idea, then, is that initial cultural differences, as manifest in the differences between the idea networks of coalition partners, will, over time, come to be eliminated by virtue of the communicative interchanges that take place between members of the coalition. As the structure of the physical and social communication network changes (e.g. to allow more efficient modes of information dissemination and social interaction to take place), it leads to corresponding changes in the dynamics of information flow and influence between members of the coalition. Ultimately, this may impact on the rate at which two or more culturally-disparate groups will converge on a common set of beliefs, concepts and values (i.e. develop a common, hybrid idea network). This convergence in the content and structure of idea networks is generally assumed to be a good thing, for cultural differences are assumed to present problems for military coalitions in terms of the efficiency of inter-agent communication and the possibility for coordinated action[9]. Inasmuch as this is true (and it may not be, of course), we should aim to countenance those types of (physical and social)

[8] Although the introduction of highly efficient communication networks may, at first sight, seem to be advantageous, Smart et al (2010) have suggested that highly efficient modes of information dissemination may actually promote forms of information sharing that undermine long-term collective problem-solving performances.

[9] Cultural differences may, for example, contribute to greater incidences of miscommunication between coalition partners (Poteet et al., 2009; Poteet et al., 2008).

communication network structure that most quickly lead to convergence at the level of idea networks.

But what factors really determine the likelihood or rate of convergence in idea networks? Should the focus of our analysis simply be on the structural characteristics of the networks that mediate inter-agent communication (i.e. the structure of the physical and social networks)? Or should we instead concentrate our attention on the nature of the idea networks themselves (as well as perhaps the psycho-dynamic forces that (like chemical bonds) make these networks more or less resistant to various forms of external influence)? One might assume that increments in the density of communication networks would lead to greater convergence at the level of idea networks, but this may not necessarily be the case, especially once one begins to factor in the psychological processes that regulate an individual's tendency to adopt new ideas.

One reason to suspect that the factors governing idea convergence may extend beyond the structural features of communication networks comes from the work on inoculation theory (McGuire, 1961). Inoculation theory was developed to account for the efficacy of various interventions in producing resistance to persuasion attempts. The basic idea is that resistance could be developed by exposing an individual to weakened forms of a message which was intended to produce attitudinal change. Thus, just as a resistance to infection can be developed by exposing an individual to a weakened form of a particular pathogen (e.g. an attenuated vaccine), attitudinal inoculation (the development of cognitive resistance to message-mediated attitudinal change) involves exposing an individual to weakened forms of a persuasive argument. This then triggers a process of counter-arguing, which then produces resistance to subsequent persuasion attempts. The key point, for present purposes, is simply that the resistance of an individual to attitudinal change can vary based on their previous exposure to particular messages and the beliefs that they may have developed in response to those messages.

The notion of cognitive advantage, which is the focus of the current paper, is somewhat different to the notion of attitudinal inoculation. It suggests that the susceptibility of an individual to cognitive change is, in part, mediated by whatever pre-existing beliefs are held by an individual[10]. These background beliefs determine the relative advantage of new ideas in terms of their being adopted by a particular community. Some ideas may be 'well aligned' with existing beliefs and are thus easily assimilated; others may not be so well aligned and are thus rejected. Different ideas essentially have different *advantages* when it comes to their propagation within particular communities. In order to predict to what extent a *particular* idea is likely to be accepted by a *particular* community we therefore need to know more about the pre-existing beliefs, concepts and values (the cognitive niche, if you like) within which idea propagation takes place. The technique of CNA is a method for doing exactly this. It enables us to develop models of the pre-existing idea networks that characterize (and indeed define) culturally-significant groupings. The availability of such models, in conjunction with information about communication network structures can lead to much better predictions about the likely rate of adoption of ideas in specific cases (e.g. the adoption of common

[10] A similar idea is explored by Smart et al (2010). They suggest that the potential for cognitive change (e.g. a change in beliefs) is determined, at least in part, by whatever pre-existing cognitive states are possessed by an individual. An individual with mutually reinforcing beliefs, which according to Smart et al (2010) leads to states of high internal cognitive consistency, is less vulnerable, they suggest, to socially-mediated forms of cognitive change.

ideas relating to the evaluation of military planning products). Inasmuch as we want to encourage convergence at the level of idea networks, it is not enough to simply engineer better, more efficient communication infrastructures. In addition to this we also need to be aware of the profile of pre-existing beliefs and values that individuals bring with them to a specific communication context. In the absence of this information we have no real way of knowing what the precise effect of cross-cultural communication will be on the idea networks of culturally-distinct communities.

Existing network-based models of information transmission and social influence can be used to study how changes in communication networks ultimately affect the dynamics of convergence at the level of idea networks. However, as we will see in the remainder of this paper, these models do not necessarily account for the relative cognitive advantage that some new ideas have by virtue of their interaction with pre-existing ideas. This shortcoming can lead to excessively optimistic predictions about the rate of convergence of ideas in a military coalition (and in other culturally heterogeneous communities), especially those that are anticipated to result from a more efficient organization of the physical communication infrastructure.

Diffusion of Innovations

Research conducted to understand the diffusion of innovations has focused on how new ideas, practices, and especially products (generally referred to as 'innovations') spread through a social system (Rogers, 1995). Diffusion is the process by which new ideas, artefacts, or practices are communicated among members of a social system, and diffusion scholars attempt to understand the processes by which diffusion occurs (an example case is study of the diffusion of hybrid corn in Iowa by Ryan and Gross (1943)). Practitioners often seek to develop programs that support the adoption of innovations, particularly when adoption decisions have health implications (an example here is the attempt to introduce the practice of water-boiling in a Peruvian village (see Rogers, 1995)), and these practitioners are typically referred to as change agents. Change agents are individuals who attempt to influence innovation decisions in a direction deemed desirable by a specific change agency. They usually seek to encourage the adoption of new innovations, but they may also attempt to prevent the adoption of undesirable innovations. Diffusion scholars conduct field research in order to understand the nature of adoption processes associated with actual innovations. These researchers focus on a myriad of issues such as the characteristics of early or late adopters, the consequences of innovation adoption, and the factors that influence an innovation's rate of adoption[11].

The example of Peruvian water-boiling mentioned above provides an exemplary case of diffusion of innovation research. In this case, the change agent was a public health worker interested in spreading the practice of water-boiling in a Peruvian village in an effort to reduce the incidence of water-borne diseases. After two years of attempting to convince 200 families to incorporate water-boiling into their daily routines, an adoption rate of only 5% was obtained (Rogers, 1995). The reason for this poor rate of adoption was traced to the pre-existing beliefs and values of the target community. In particular, an existing belief among the villagers was that hot water should only be drunk when someone was sick and that villagers who were not ill should only drink cold water. The

[11] An innovation's 'rate of adoption' is a central metric used in innovation diffusion research. In fact, the 'innovativeness' of an innovation is defined by its rate of adoption. The rate of adoption is typically defined as the time taken until a criterion percentage of adoption has been reached.

novel practice of drinking boiled water was difficult for the villagers to accept because water boiling made water hot (even if only temporarily), and that contrasted with their existing beliefs that healthy individuals should only consume cold water[12].

Diffusion researchers have found cases like this to be all too common. In order to understand such outcomes Rogers (1995) described a process model of innovation-decisions that consists of five stages:

1. *Knowledge*: The decision maker becomes aware that the innovation exists and has some understanding of how it works.
2. *Persuasion*: The decision maker forms a positive or negative attitude towards the innovation.
3. *Decision*: The decision maker makes a commitment to adopt or reject the innovation.
4. *Implementation*: The decision maker acts on a commitment to adopt.
5. *Confirmation*: The decision maker re-evaluates the earlier adoption decision. This can lead to four states depending on the earlier decision, as follows:
    a. If adopted earlier, then continued adoption or discontinuance.
    b. If rejected earlier, then adopted later or continued rejection.

In terms of the notion of cognitive advantage, we can think of the pre-existing beliefs and values of a community as coming into play during steps 2 and 3 of this process model. The notion of cognitive advantage thus helps explain the factors that contribute to the formation of positive and negative attitudes (step 2) towards an innovation, as well the likelihood of adoption decisions actually being made (step 3).

Diffusion scholars have also recognized a number of factors that influence innovation adoption rates. These include the role that specific individuals play in terms of innovation adoption decisions and the features of the social network in which the new innovation (e.g. idea) is to be introduced. In terms of the former issue (the role that individuals play within a particular community), diffusion researchers have sought to classify individuals with respect to a number of adopter categories. These categories include innovators, early-adopters, the early majority, the late majority, and laggards. Innovators actively seek new ideas and are able to tolerate more uncertainty than members of the other categories. Later adopters base their decisions primarily on the evaluations of earlier adopters (Rogers, 1995). Rogers argues that the most innovative members in a social system are often seen as somewhat deviant with respect to social norms, and they may therefore lack credibility. As a result, innovators may only play a small role in innovation diffusion processes; large parts of the process may be driven by other social actors, such as opinion leaders or trend-setters. Opinion leaders are members of the social system who are consistently able to influence other individuals' attitudes or decisions. They are widely connected within the community and are well

[12] The Peruvian water boiling case is an interesting one because it directly highlights the fact that a community may be differentially resistant to the introduction of a new idea based on a community's pre-existing beliefs, values and practices. In accounting for innovation adoption outcomes it seems important to consider not just the structural and temporal aspects of communication (e.g. the connectivity of a community or the frequency of communication between community members), it is also important to consider the pre-existing beliefs and values those members bring to communicative contexts.

aligned with the norms of the community. The failure of the Peruvian water-boiling innovation to achieve significant levels of diffusion can perhaps be attributed to the lack of support by important agents in the social system, such as opinion leaders.

The structure of a social system is also expected to exert a strong influence on the rate of adoption. For example, scale-free social networks are fairly efficient in terms of their ability to disseminate information, so networks with such properties are expected to produce faster adoption rates than others. Although some simulation-based research has attempted to shed light on the relationship between aspects of network structure and innovation diffusion processes (e.g. Amblard & Deffuant, 2004; Franks et al., 2008), there are few studies, at the present time, that describe precisely how network structure affects innovation diffusion, especially in the context of real-world human social groups. Importantly, although diffusion field researchers are sensitive to the possibility that factors such as cognitive processes may affect adoption, such considerations tend to be downplayed or ignored in the context of computer simulation studies.

Social network factors that are thought to influence the rate of adoption of innovations include the following:

- **Type of Innovation-Decision**. Decisions within the social system can be made in one of three ways:
    - Optional innovation-decisions: Choices to adopt or reject innovations that are made by individuals independently of other members of the system.
    - Collective innovation-decisions: Choices that are made by consensus among the members of a system.
    - Authority innovation-decisions: Choices that are made by relatively few individuals with high status and power.

  These three types of innovation-decision can be conceived as ranging on a continuum reflecting the amount of responsibility an adopting individual has for the innovation-decision (complete for optional, to none for authority). In principle, authority decisions are the fastest since the fewest people actually have to come to an agreement.

- **Similarity Amongst Participants.** This is referred to as homophily in the diffusion and social network literature. Homophily is the degree to which individuals in the system (including the change agent) possess common attributes, such as sharing personal and social characteristics. The rate of diffusion is higher when the change agent and adopters are more similar, as well as when adopters within the social system are more similar to each other. The homophily assumption is also taken as axiomatic in many simulations of social belief dynamics (Axelrod, 1997; Dittmer, 2001; Hegselmann & Krause, 2002), and it has been identified as important in terms of preventing so-called ‘cognitive convergence’ (Parunak, 2009). In spite of this, the level of empirical support for the homophily assumption is somewhat weak, and further work is clearly needed.
- **Social Network Interconnectedness.** This factor reflects the degree to which members of the system communicate with each other. It can also refer to the degree of influence that opinion leaders actually have within the system.

If an innovation is successfully diffused, then the cumulative adoption percentage over time typically exhibits an S-shaped function (Bass, 1969). This is taken to reflect an underlying normal distribution of adopters, with smaller variance producing more rapid rates of adoption (see Figure 3). If an innovation is adopted but later rejected, the cumulative percentage drops. The implication of this is that if an innovation is ultimately rejected by the social system, the cumulative curve drops back towards zero. Examples of this could include fads or manias in which large proportions of the population adopt an innovation, but later reject it once the fad has passed (e.g. bell bottoms), or innovations that are initially taken up by early adopters, but later fail or are out-competed in the marketplace (e.g. the HD-DVD format saw a high rate of initial adoption until it was dropped by manufacturers in favour of the Blu-ray disc format).

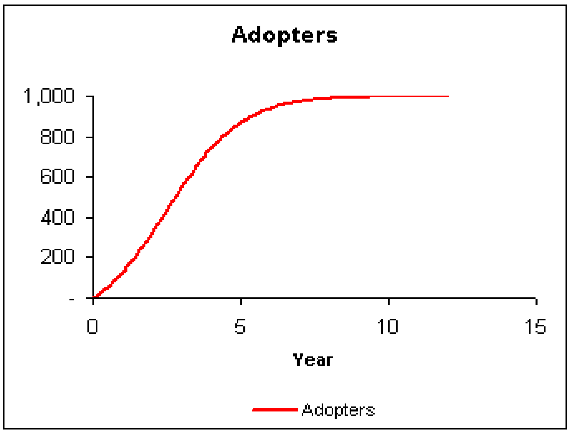

Figure 3: Diffusion function showing the rate of adoption of innovations. The number of adopters is cumulative.

The Bass Diffusion Model

Although Rogers' (1995) model describes the mechanisms that drive the spread of innovations, it does not include a formal quantitative component. In 1969, inspired by Rogers and other diffusion theorists, Frank Bass developed a quantitative model that has since been the benchmark for quantifying the rate of adoption of an innovation within a population.

The typical representation of the Bass Diffusion model is a differential equation that describes the adoption rate as:

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

The left side of this equation is the proportion of people that adopt a particular innovation at time *t*. This proportion depends on two factors: *p* and *q*. *p*, known as the coefficient of innovation, is an aggregate variable containing all the factors that contribute to diffusion that are not impacted by the number of previous adopters. Such factors include the intrinsic value of the innovation and advertising. On the other hand, *q,* the coefficient of imitation, is moderated by the proportion of people who have already adopted the innovation at time *t* (*M* is the total number of possible adopters and *A(t)* is the number of people who have adopted at time *t*). Based on numerous empirical studies, bounds have been placed on both of these variables. The coefficient of innovation, *p,* is typically less than .01 and the coefficient of imitation, *q,* typically falls between 0.3 and 0.5.

Perhaps the most profound contribution of the Bass model is its focus on diffusion being a function of the proportion of people who have already adopted. This factor is important because the chance of an individual adopting an innovation goes up as more adopters are present in the population. The rate of growth declines, however, as the proportion of individuals yet to adopt the innovation goes down.

Implications/Limitations

The diffusion of innovations research literature provides some insight into the mechanisms of information transmission within a social system. However, most formal diffusion of innovation models do not explicitly account for key factors deemed important to the process of idea change in social networks. This is despite the fact that such factors have been fairly well described at the conceptual level. Factors not expressed in the Bass Diffusion Model, for example, include the content of messages and the distribution of existing beliefs in the population. Such factors are likely to influence the susceptibility of an individual to idea adoption.

Memetics

In 1976, Richard Dawkins coined the term 'meme' to reflect the similarity between genetic transmission and idea transmission. The main objective 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. Although Dawkins did not expand upon the meme concept himself, he spawned a small movement of researchers and authors who began referring to the movement as the science of memetics (e.g. Susan Blackmore, Aaron Lynch, and Richard Brodie). Many of these memeticists have developed computational models to explore the mechanics behind memetic modes of transmission (e.g. Cavalli-Sforza & Feldman, 1981).

The concept of a meme roughly reflects that of an idea, but what makes it unique from a concept, belief, or value is that a meme is a postulated abstraction that operates according to the rules of memetics. These rules mirror evolutionary mechanisms in biology. Importantly, memetics places the focus on the message, rather than on the agent. In a sense, the agents that hold a belief are simply carriers or propagation agents of that belief. Chain letters are examples of memetic artefacts, because once started they include the instructions (e.g. 'copy this and send it to ten strangers') and admonishments (e.g. 'it is bad luck to break the chain') needed to continue the propagation process; the originator of the letter quickly becomes irrelevant and unable to prevent further propagation, and the extent to which a recipient follows the instructions illustrates the fitness of the meme. Some mechanisms frequently referred to in the memetic literature include:

- **Phenotypes and Alleles.** In memetic transmission, the 'offspring' of a meme vary in their appearance. Although the meme is being transmitted from parent to child, the child's appearance, or phenotype, can be different. A meme contains a number of characteristics called alleles, which are randomly sampled when the meme is transmitted to the child. The variability in allele combinations is what causes variability at the phenotypic level.
- **Mutation.** Similar to one of the key mechanisms in Darwinian evolution, ideas vary as they are transmitted from one person to another. Usually the variation is minor because a child meme shares most of the features of its parent, and child memes are easily

likened to their parents when compared to unrelated memes. Idea mutation often displays randomness, which is exactly how biological mutation operates. Biological mutation is always random, but idea mutation need not necessarily be so. Mutations of ideas often occur for particular reasons, such as to solve problems (see Cavalli-Sforza & Feldman, 1981). The notion of idea mutation is very similar to the concept of an innovation in the diffusion of innovations literature, and, as was discussed above, innovations are often purposively brought about by change agents who have specific goals in mind.

- **Selection.** Some ideas are more likely to survive than others. The survival of an idea is based on how 'fit' it is. In computational memetics models, a meme's fitness function generally refers to the likelihood of its offspring surviving long enough for them to produce their own offspring, compared to the offspring of other memes. So, as in biological evolution, a fit idea is one that contains particular characteristics that promote the reproduction of its offspring.
- **Lamarckian Properties.** Unlike genes in biological evolution, a meme can be modified or possibly activated or deactivated within a generation. That is, human meme carriers can adapt their ideas to deal with new information (Gabora, 1995).
- **Drift.** If multiple finite-size populations exist that begin with the same set of initial conditions and operate according to the same mechanisms (including the same constraints driving selection), completely different sets of ideas can emerge between the populations. This notion of drift occurs because of sampling error when a parent meme produces offspring (Cavalli-Sforza & Feldman, 1981). As noted above, a random sample of alleles are taken from the parent to create the child meme. The result of this sampling error is that the drift phenomenon is much stronger in populations with smaller numbers of constituents.

Unlike genetics models, memetics models focus on both horizontal (intra-generational) and vertical (inter-generational) forms of transmission. Vertical transmission does not imply that ideas are necessarily 'in the genes' or that most ideas are likely to be transmitted from parents to offspring via social mechanisms. However, there is some importance attached to modelling the perpetuation of ideas over generations. In many cultures, the family unit is more influential than potential influences from outside the family, and the impact of a parent's idea set on a child's may be significant. Furthermore, particular types of ideas (e.g. myths, folklore, and stories) are likely to be transmitted vertically, and these ideas often perpetuate important cultural beliefs and values that significantly contribute to behaviour.

The primary mechanism for memetic transmission is imitation (Blackmore, 1999); however, other mechanisms have been recognized by memeticists, including social learning and instruction (Heyes, 1993). Gabora (1995) incorporated cognitive mechanisms that resemble schema development and mental simulation into an agent-based memetic model. The schema mechanism is developed through the recognition of repetition of ideas in the world. Once a schema is formed, the agent adapts (mutates) incoming ideas to be consistent with the schema. The mental simulation component allows agents to anticipate the impact of adopting a particular meme.

Cavalli-Sforza and Feldman Model

In 1981, Cavalli-Sforza and Feldman published a detailed account of a model of idea transmission that incorporated evolutionary mechanisms. The primary driver for transmission of an idea within a generation was an *n*-state probability table based on the following function:

$$p = 1 - |1 - g|^{nu_t} \quad (2)$$

where *p* is the probability that an individual's belief state will be transformed (i.e. imitate another's) after *n* contacts. *g* is the probability of transformation at each contact, and u_t is the proportion of people the individual can come in contact with who have already achieved the target belief state. As in the Bass Diffusion Model, the rate of transformation depends on the number of constituents who have already transformed (see Figure 4).

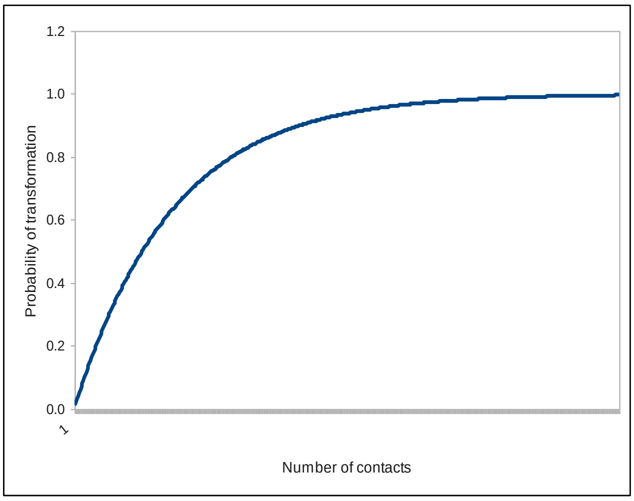

Figure 4: Cavalli-Sforza and Feldman's transmission function. This is the form of the function when the probability of transmission for each interaction is 0.1 and the proportion of individuals who already hold an idea is 0.1.

Like the aforementioned function that drives transmission, a simple function can also drive selection. The proportion of beliefs that survive selection for a single generation is:

$$u'_t = \frac{u_t(1+s)}{1 + su_t} \quad (3)$$

where u_t is the proportion of beliefs before selection, and *s* is a degree of fitness. Therefore, as *s* increases, the belief is more likely to survive.

Combining both of these functions (as well as more sophisticated approaches to selection), Cavalli-Sforza and Feldman demonstrated how the 'life' and 'death' of ideas can be likened to an evolutionary selection process.

Implications/Limitations

The memetic approach to information transmission is very reliant on the genetic/evolutionary metaphor. As Dawkins originally noted, there is a significant overlap in the dynamics of both genetic and idea transmission. However, over-reliance on the metaphor has caused some important aspects of information transmission to be ignored.

An important implication of the memetic approach is that the likelihood of an idea's survival, thus transmission, is heavily dependent on the characteristics of the idea itself. As Lynch (1996) points out, certain ideas contain features that affect the degree to which they propagate. For example, certain ideas contain the attribute of 'proselytism'. That is, part of the idea itself is to spread the idea. Also, some ideas may contain attributes that preserve the state of the idea (i.e. prevent it from mutating) or prevent the possibility of idea rejection, such as the idea that one should 'never question the Bible'. Lynch also suggests that some ideas have a 'cognitive advantage' if they appear to be well-founded to people who are exposed to them. However, although this factor is mentioned, it has (to our knowledge) never really been developed as an explicit modelling parameter in memetics-based models. Something similar to the notion of cognitive advantage is found in the diffusion of innovations literature. For example, Rogers' (1995) innovation-decision process model includes a 'persuasion' component to describe the formation of a positive attitude towards a new idea (or other innovation). The general issue of cognitive advantage is thus appreciated as important at the conceptual level; however, no precise way of independently measuring and modelling the cognitive advantage of an idea is currently offered by either memetics or innovation diffusion theorists.

Cultural Transmission

A further class of models has recently emerged, which are largely independent of both the memetics and diffusion of innovation models. Robert Axelrod refers to these models as models of 'cultural transmission'. Axelrod acknowledges the complexity involved in the spread of ideas, citing such mechanisms as fads, extremist perspectives, drift, geographic isolation, and specialization. However, the model he proposes (Axelrod, 1997) is more abstract, and focuses on a general principle of similarity, which is believed to be ubiquitous. Rogers argues that the principle of similarity is the overarching mechanism in idea transmission because it is the driving principle in human interaction. In other words, humans would not even interact with others who held divergent views to themselves, let alone consider the views of those individuals.

As simple as the model sounds, Axelrod produced simulations that showed how a simple rule (one that would at first appear to lead to complete convergence across a population) can produce multiple populations who hold completely different sets of ideas. For example, in Figure 5, each square represents a unit (person, village, etc) that holds a particular 'idea set'. A unit's idea set is an array of features with each feature having a certain trait (value). The colour of each unit is a composite representation of the unit's idea set; therefore, units with more similar sets of features will be more alike in terms of their colour. The top part of Figure 5 shows the initial state of the units in the system at system initialization (the state of each unit is randomly generated). The following procedure then governs the evolution of the system:

- Select a unit at random, and then choose one of its neighbours, again at random.
- Determine the feature similarity of the units (this is essentially the proportion of features in the unit's and neighbour's idea sets that are the same).

- If the units interact[13], then select one of the features of the neighbouring unit (at random) and assign it to the currently selected unit.

The results of the simulation after system stabilization are shown in the bottom half of Figure 5. Here we can see one dominant region of convergence (dark area) as well as two smaller regions. Despite the existence of local rules that promote convergence, the model shows that polarized regions of ideas can, in fact, form. The explanation for this goes beyond the size of the geographic region (lattice) and the range of interactions. One factor that impacts the number of regions that ultimately form is the number of possible features. As the number of features increases, the likelihood of different regions forming decreases. This occurs because a higher number of features increases the likelihood of neighbouring sites containing a shared feature. Another factor that impacts the development of multiple regions is the number of traits/values that each feature can take on. When there are fewer traits, there is a greater likelihood that neighbours will share a common feature and, therefore, interact.

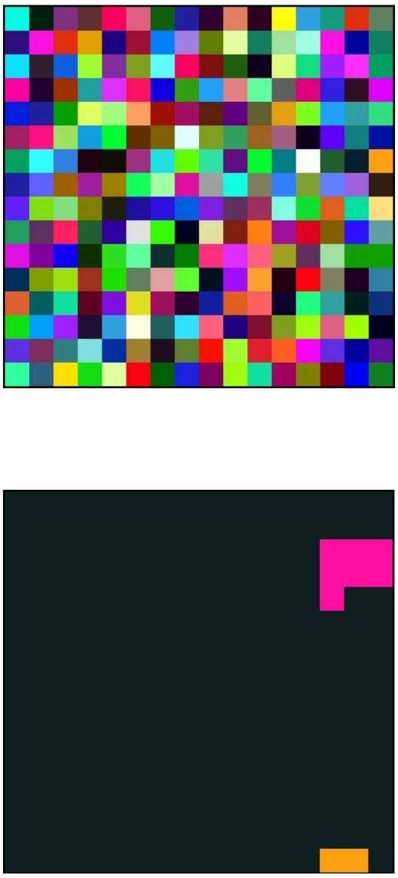

Figure 5: Lattice representation of Axelrod's simulation with agents each having 5 ideas with 9 possible traits per idea. The top panel shows a random initialization of ideas for each unit. Similar colors represent similar initial sets of ideas. The bottom panel shows the result of a simulation using Axelrod's transmission rules.

Axelrod interpreted these two factors as describing a general notion of cultural complexity. For example, the number of features could be interpreted as a generic form of cultural diversity, with

[13] The proportion of overlap is used to determine if the two sites interact (in the case of two units that each have 5 ideas with 2 ideas in common, the probability of the two units interacting is 0.4).

the implication being that the more diverse a culture is, the more likely it is that it will contain elements that overlap with other cultures.

Implications/Limitations

Axelrod's model of idea transmission emphasizes two mechanisms, which are both suggested in the diffusion of innovation and other literatures. The first mechanism is similarity between agents, and it is the driving force in transmission of information between units in Axelrod's model. The likelihood of units even interacting is determined by the degree of overlap in adjacent units' ideas. A similar interaction dynamic has emerged in the opinion dynamics literature, where agents are prevented from interacting unless the opinion of two agents is within certain confidence limits (e.g. Dittmer, 2001; Hegselmann & Krause, 2002). The second mechanism relates to the issue of network connectivity. Although Axelrod's model (as it is presented here) limits the transmission of information to units in the immediate geographic vicinity, the same principle can be applied to social networks in which network nodes are connected to any number of other nodes.

A limitation of Axelrod's model concerns the characterization of an idea set. In this model, an idea set is an array of unrelated features in which individual elements can be changed independently of other elements. As discussed below, we see ideas sets as consisting of complex networks of inter-linked ideas (i.e. idea networks), and so the assumption of independence between ideas can be seen as something of an oversimplification[14].

Cultural Epidemiology

Some scientists have noted that memetic-type approaches to information transmission have largely ignored much of the psychological literature (e.g. Atran et al., 2005; Sperber, 1996). The dynamics of persuasion, and the impact of reasoning and decision making tend not to be well addressed in memetic theories. Cultural epidemiology has been described as a parallel approach to memetics that aims to achieve greater psychological realism in its theoretical constructs and processes (Sperber, 1996).

Atran, Medin, and Ross (2005) define cultural epidemiology as a means to study culture using distributions of ideas, beliefs and behaviours in an ecological context by focusing on cognitive processes such as inference, reasoning, and perception. Cultural epidemiology focuses on the development of cultural models, and it can be seen as a direct extension of cognitive anthropological research (e.g. D'Andrade, 1981). With respect to model dynamics, Sperber (1996) notes that individuals' private mental models become public in the form of shared representations and artefacts, and whether it occurs through common experience or communication, what ultimately develops are shared representations. That is, there are sets of ideas that exist in the heads of many individuals, with little variation between the heads of individuals. Similar to the notion of a replicator in the memetics literature, individual variants of a common idea share noticeably more properties with each other than with other, unrelated, ideas. Another way of looking at this is to see the ideas of individuals within a group as slightly different versions of a common idea that is shared by all

[14] Something similar is suggested by Smart et al (2010). They suggest that beliefs are connected together in ways that reflect the logical or causal structure of the domain to which the beliefs apply. These linkages create dependencies between the beliefs which, in extreme cases, may make an individual relatively invulnerable to socially-mediated forms of cognitive change.

members of the group. For example, if Larry, Curly, and Moe are part of the same social group and they have all been exposed to the idea of a unicorn, then each individual's representation of the unicorn may be somewhat different (e.g. Larry's unicorn may be white, while Moe's may be gray; Moe's unicorn may have wings, while Larry's and Curly's do not). Despite these individual differences, however, there is likely to be enough of an overlap in Larry, Curly and Moe's unicorn-related ideas to distinguish them from ideas relating to other mythological beasts (e.g. ideas about minotaurs).

Sperber (1996) also notes that there is often not a clear demarcation between individual and culturally-shared representations. Some representations may be shared by only a handful of individuals, and the degree to which there is consensus towards particular ideas in a population can vary greatly. For example, Mullahs possess specialized knowledge pertaining to their role within Islamic cultural groups. This knowledge is not widely shared by everyone, but it would still be considered cultural. The result of this is that the focus of cultural epidemiology is on the full distribution of ideas in the population, not just on the most widely shared ideas (Sperber, 1996).

The development of locally-shared idea networks among small groups within a region has also been found to result (at least in part) from pre-existing culturally-shared knowledge. In a study of three Mesoamerican cultural groups, Atran, Medin, and Ross (2005) discovered that different mental models of forest ecology developed as an interrelated function of historical context, belief precedent, and the makeup of social networks between local groups. In particular, Atran and colleagues studied folk biological knowledge of three groups living in the lowland rainforest of Guatemala: Itza' Maya (the original natives), Spanish-speaking immigrant Latinos, and immigrant Q'eqchi' Maya. The Itza' Maya possessed a highly-sophisticated understanding of folk biology in the region, and had long adopted sustainable ecological practices in the rainforest. Interestingly, the Latinos were closest to the Itza' Maya in terms of folk biological knowledge, whereas the Q'eqchi' Maya held the most divergent ideas (and the least sustainable practices). This latter finding appears to be due to the fact that the Q'eqchi' held onto their pre-existing, culturally-shared idea network that had formed prior to their migration from the highlands (a distinct ecological area). The Latinos, on the other hand, had little in the way of pre-existing knowledge or beliefs that was remotely pertinent to the region; hence, they formed closer social interactions and social networks with the native Itza' Mayans. As a consequence, they learned more about the local ecological niche from the Itza' than did the Q'eqchi', and they adopted practices better suited to the ecological niche of the rainforest. In this way, the Itza' Mayan ideas had a *cognitive advantage* relative to the pre-existing idea networks of the Latinos.

Cultural Network Analysis

CNA represents a specific method for building cultural models that stems directly from cultural epidemiological theory. CNA allows scientists to construct culturally-shared mental models given data from individual group members (Sieck et al., 2010). These 'cultural models' for groups and wider populations are typically depicted as a network representation of the culturally-shared concepts, causal beliefs, and values that influence key decision outcomes (for example, beliefs associated with the positive evaluation of a military coalition plan (see Rasmussen et al., 2009)). CNA encompasses both qualitative, exploratory analysis, and quantitative, confirmatory analysis. The specific techniques used to achieve each step in the analysis depend on whether the cultural researcher is employing exploratory CNA or confirmatory CNA.

A primary goal of exploratory CNA is to develop an initial understanding of the concepts and characteristics that are culturally relevant within the target domain of interest. In exploratory CNA, concepts, causal beliefs, and values are extracted from interviews and other qualitative sources. Semi-structured interviews employ questions intended to elicit the antecedents and consequents of concept states. Questioning along these lines draws out a more comprehensive set of ideas than what would typically be verbalized in standard think-aloud procedures, and it is particularly effective at drawing out perceived causal relations. The interview-based approach can also be combined with 'value focused thinking', which derives from decision analysis, to elicit values and objectives directly, along with the causal beliefs that link more fundamental values with the means intended to achieve them (Sieck, 2010; Sieck et al., 2010). Qualitative analysis and representation at this stage yields insights that can be captured in initial, informally-structured cultural models.

Influence diagrams have proved useful for representing mental models, especially those that are relevant to key judgments and decisions (Bostrom et al., 1992), and these have also become an important representational format for depicting cultural models. In an influence diagram, the nodes are linked by arrows that represent local causal influences. That is, the value of the concept at the rear-end of an arrow affects the value of the concept at the arrow's head. Fully-specified influence diagrams can also represent numerical quantities, but the basic structure is useful for communicating basic information about a cultural model. Specifically, an influence diagram provides a relatively simple and useful representation of a cultural model that includes key judgments and decisions of interest to the researcher, as well as the culture-specific concepts, values, and (causal) beliefs that are typically used to explain, account and justify those decisions within a particular population. An example of a qualitative cultural model that was developed to support the identification of cultural differences between US and UK military planners is presented in Figure 6 (the model is presented in the form of an influence diagram).

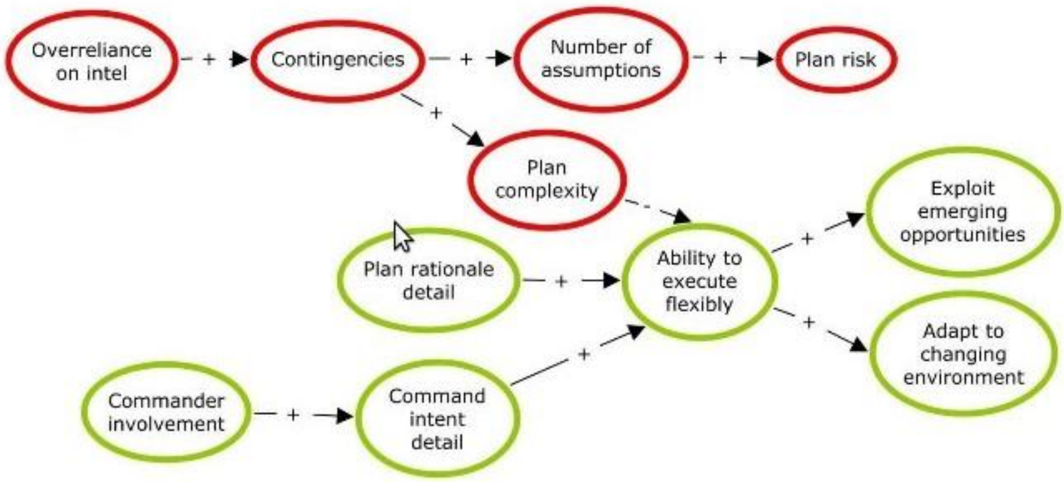

Figure 6: A UK cultural model of a 'good plan'.

Confirmatory CNA serves to test the structure of previously developed qualitative cultural models, as well as to elaborate the models with quantitative data on the prevalence of ideas in the target population(s) of interest. In confirmatory CNA, specially-designed structured questionnaires are used to conduct 'causal belief surveys'. The aim here is to obtain systematic data that can be subjected to subsequent statistical analysis. Statistical models, such as cultural consensus theory[15] and mixture models[16], are employed in confirmatory CNA to assess the patterns of agreement from the causal belief surveys. Such statistical models are also used to derive statistics describing the distribution of concepts, causal beliefs, and values within the focal population(s).

Influence diagram representations of the cultural models can be constructed in confirmatory CNA, just as they can in the case of exploratory CNA. In the case of confirmatory CNA, however, the influence diagrams illustrate the quantitative properties as revealed by statistical analysis, in addition to the qualitative structure elucidated by exploratory CNA. This extended form of the influence diagram represents the 'culturally correct' concepts, values, and causal beliefs for each cultural group that was revealed by (e.g.) mixture modelling. Furthermore, the numerical probability values in the influence diagram indicate the prevalence of each idea within a particular cultural group. The result is a description of the full distribution of ideas, with probabilities indicating the consensus on any particular causal link (or node). The degree of consensus can be interpreted as the likelihood that a particular idea is active in a particular constituent's (i.e. individual's) mind and of the prevalence of the concept, value or belief within the wider cultural group to which the individual belongs.

CNA provides an integrated collection of techniques and procedures that can be usefully employed to build static cultural models in virtually any knowledge domain, and such models can be used in a wide variety of applications contexts (Sieck, 2010). For example, CNA has demonstrated its utility in the design of processes and systems to support multinational collaborative planning (Rasmussen et al., 2009), cultural training development (Rasmussen et al., 2010), and the design of effective communication strategies (Sieck, 2010). As emphasized throughout this paper, CNA can also be used to improve our predictive and explanatory models of idea propagation within *particular* communities. A primary contribution of CNA to modelling the spread of ideas is that it provides comprehensive representations of the culturally-shared knowledge that new ideas will interact with during the course of idea propagation. This is an important part of the development of predictive models. For just as the success of a new species in a particular ecological niche is determined by the existing nexus of inter-species relationships, so too the acceptability of a new idea is determined by the existing nexus of beliefs and values adopted by a particular community. In order to better

[15] Cultural consensus theory is a collection of formal statistical models that has long been used within cognitive anthropology to assess the extent of agreement in knowledge and beliefs among a set of respondents (Romney et al., 1986).

[16] Mixture modelling provides an alternative approach to cultural consensus theory. It permits the direct segmentation of cultural groups based on clusters of consensus (Mueller & Veinott, 2008; Sieck & Mueller, 2009). Mixture models have been applied in many scientific fields, including marketing, biology, medicine, and astronomy. A mixture model, or 'finite mixture model', is given as a combination of different groups, each described by a distinct probability distribution. Mixture models sort through the data and group them into sets of relatively homogeneous cases or observations. In cultural modelling applications, the distinct segments resulting from the analysis represent cultural groups (i.e. groups defined by the similarity of their ideas), and so the technique has sometimes been referred to as 'cultural mixture modelling' for applications in the cultural domain (Mueller & Veinott, 2008).

understand the cognitive advantage of new ideas, we must therefore develop a better understanding of the 'cognitive niche' into which new ideas are to be introduced. CNA is a technique that enables us to do just that. It enables us to analyze and represent the idea networks of specific cultural groups, and it provides one means by which the cognitive advantage of new ideas may be evaluated.

Conclusion

A key aim of this paper has been to identify approaches that enable us to better represent and understand the dynamics of idea propagation within particular communities. We have argued that one such approach involves the development of idea networks using the technique of CNA. Idea networks consist of the values, beliefs and concepts of individuals within a focal population, and they are important because they contain information that is relevant to our understanding of how specific beliefs, values and concepts propagate throughout a social network. In particular, idea networks provide information about the pre-existing culturally-entrenched beliefs, concepts and values that exist in a population, and these are important because they determine the cognitive advantage of new ideas. It is the cognitive advantage of an idea that determines the rate at which ideas are transmitted, as well as their tendency to become established in a particular community.

The notion of cognitive advantage is, unfortunately, absent from many models of information transmission within the social network literature. Most models focus exclusively on the role of structural issues, such as how network topology affects the rate of information dissemination. By appreciating the cognitive advantage of specific ideas, we may begin to better understand the propagation dynamics of ideas within specific, real-world communities. Such considerations hopefully take us a step closer towards the development of more ecologically-realistic models of group-level cognitive dynamics.

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