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Modelling the Spread of Memes:

How Inovations are Transmitted from Brain to Brain

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Abstract

Memes, elements of a culture that may be considered to be passed on by non-genetic means, especialy imitation, inhabit brains and moves from one brain to other brains. Therefore, their structure and dynamics are prone to formalization and modeling techniques, taking into account the properties of neural systems. Moreover, the transmission dynamics of memes is rather similar to the one of infectious diseases. Therefore, the same formalisms applied to the latter could be adpated to the former. We applied a classical deterministic model to describe the spread of a new unit of culture, the hybrid corn in the State of Iowa in the years of 1930s and 1940s. The model describes this spreading of the new meme with good accuracy, which demosntrate the feasibility of the appplication of dyancmi models developed to describe the dynamics of the spread of pathogens to the spread of memes.

1. Introduction

Humans are capable of imitation and so can copy from one another ideas, habits, skilled behavior, inventions, song and stories. These are all ‘cultural units’ which were renamed as *memes*, a term which first appear in Richard Dawkins’ book *The Selfish Gene* [9]. In that book, Dawkins dealt with the problem of biological (or Darwinian) evolution as *differential survival of replicating entities* [9]. By replicating entities Dawkins meant, obviously, genes. Then, in the final part of his book, Dawkins asked the question ‘*are there any other replicators on our planet?’*, to which he answered ‘*yes’*. He was referring himself to cultural transmission and fancied another replicator – a unit of imitation [3], [4]. Dawkins first though of ‘*mimeme’*, which had a suitable Greek root (Dawkins’ words) but he wanted a monosyllable word which would sound like ‘gene’ and hence the abbreviation of mimeme – meme. A revolutionary new concept (actually, a truly Kuhnian paradigm shift) was born. Like genes, memes are replicators, competing to get into as many brains as possible.

Although the concept of memes represents an important step in the process of understanding the diffusion of cultural traits and ideas, either new or old ones, its formalization is still insufficient in the sense that it neither addresses the structure of memes as informational units nor proposes a mechanistic explanation for its spread.

It should be noted that memes inhabit brains and moves from one brain to other brains. Therefore, their structure and dynamics are prone to formalization and modeling techniques, taking into account the properties of neural systems. Moreover, the transmission dynamics of memes is rather similar to the one of infectious diseases. Therefore, the same formalisms applied to the latter could be adpated to the former. This is the main objective of this paper.

1.1 The definition of meme

The *Oxford English Dictionary* contains the following definition:

meme *An element of a culture that may be considered to be passed on by non-genetic means, esp. imitation*.

Memes can be thought as information patterns, held in an individual’s memory and capable of being copied to another individual’s memory. The new science of memetics is a theoretical and empirical science that studies the replication, spread and evolution of memes. As the individual who transmitted the meme continues to carry it, the process of meme transmission can be interpreted as a replication, which makes the meme a truly replicator in the same sense as a gene. Like the evolution of traits by natural selection of those genes that confer differential reproductivity, the cultural evolution also occurs by selection of memes with differential reproductivity, that is, those memes with the highest copying rates will take over those with lower copying rates.

Dawkins listed three characteristics for any successful replicators:

a) copying-fidelity: the more faithful the copy, the more will remain of the initial pattern after several round of copying;
b) fecundity: the faster the rate of copying, the more the replicator will spread; and
c) longevity: the longer any instance of the replicating patterns survives, the more copies can be made of it.

Just think of the example provided by Blackmore [4], the song 'Happy Birthday to You' and you have a tremendously successful replicator, already copied (with high-fidelity) thousand of millions of times (high fecundity) all over the world for several decades (longevity). In these characteristics, memes are similar to genes and the new science of memetics imitates (a metamemetics phenomenon?) to a certain extent, that of genetics.

1.2 Imitation and Mirror Neurons

Rizzolatti and Arbibi [16] have described a class of neurons that are activated when the individual either execute or see the execuction of an act, and they called them *mirror neurons*. These cells are neither sensory nor motor neurons. They play a role of linking sensory recognition to motor action. Therefore, they are high order associative units.
Mirror neurons are being proposed to play a central role in the process of imitation because they act as hubs in the integrative process of performing what one sees.
In the same way, in humans and other animals capable of producing sounds, another class of mirror neurons link sensory recognition of sounds to the motor action for the production of the same sound.
This is the neural base of imitation.

1.3 The brain as a Distributed Intelligent Processing System

The recent findings about the physiology of the brain as disclosed by many different brain mapping techniques, such as PET, fMRI, EEG mapping, etc, allowing many cognitive functions to be studied in the normal and disabled human being, have shown that the brain may be as a Distributed Intelligent Processing System [18]. This kind of system is composed of subsystems or agents having some specialization in solving defined problems because they have specific tools for acting. For example, some agents are required to set goals; others to define plans or strategies; others to put these plans or strategies into action; others to evaluate the result of these actions; etc. DIPS reasoning is the cooperative activity among as much as possible decentralized and loosely coupled collection of agents that may provide the solution of a given problem. Decentralized means that both control and data are logically and often geographically distributed; there is neither global control nor global data storage. The reasoning intends to build models in which the control structure emerges (is learned) as a pattern of passing messages among the agents being modeled. Task distribution is an interactive process, a discussion carried on between an agent with a task to be executed and a group of agents that may be able to execute the task.

1.4 Memetic channels

Communication among **DIPS**' agents is established by means of two main strategies [17]:

a) mail addressing: both the sending and the receiving agents know themselves, that is to say they have the capacity to address messages specifically to each other. Imitation is mainly a mail addressing memetic channel, since it is based in individual "contacts"
b) Broadcasting: agents deliver messages that are not specifically addressed to another defined agent, but to those interested in the subject. Instruction is the first mechanism to implement a broadcasting memetic channel since the action of one organism is communicated to a group of peers. Language, by supporting teaching, increases the capacity of a broadcasting memetic channel. Writen widely broads this capacity.

2. How memes spread (mathematical models and memetics)

One of the first approach to the spread of ideas by dynamical systems was those due to Rogers [20], whose classical book, the *Diffusion of Innovations*, is a landmark of modeling the spread of ideas and concepts. Actually, when Rogers wrote the first edition of his book 50 years ago [19], the very concept of meme has not been proposed yet. In its fourth edition [20], however, this book still miss the idea of meme. Nothwithstanding this fact, the spread of inovations is not but an alternative to memetics dynamics. The the so-called logistic model of innovations spread is one way of simulating this dynamics.

An intersting example of the spread of a new meme is represented by the case of hibrid corn in Iowa farms in the late twenties/early thirties, described by Rogers [20]. At the time, farmers choose the best seeds from a given year yield to the follwoing year seeding. The hibrid corn seeds, in contrast, besides given a greater yield, were handicaped by the need of bying new seed every year. The example of hibrid corn is described with details in the book of Rogers. In the following analysis, we revisit the spread of hibrid corn in Iowa, applying an original model.

In this model, it is assumed a total population *n*, a fraction *a* of which adopted a given novelty. Therefore, there remains a fracion *n – a* individuals ´ ´susceptible` to the innovation. The model also assumes a contact rate λ between ´infected` and ´susceptible` individuals. The rate of growing of adpters is, therefore given by:

$$\frac{da(t)}{dt} = \lambda a(t)(n - a(t)) \qquad (1)$$

which can easily be solved as:

$$a(t) = \left[1 + \frac{(1 - a_0)}{a_0}\exp(\lambda t)\right]^{-1} \qquad (2)$$

which is one of the forms of the logistic equation. When the rate of contact varies with time the equation is :

$$a(t) = \left[1 + \frac{(1 - a_0)}{a_0}\exp\left(\int_0^s \lambda(s)ds\right)\right]^{-1} \qquad (3)$$

Figure 1 illustrates the model's simulation, in which the number of farms adopting the hybrid corn in Iowa increases in a logistic fashion.

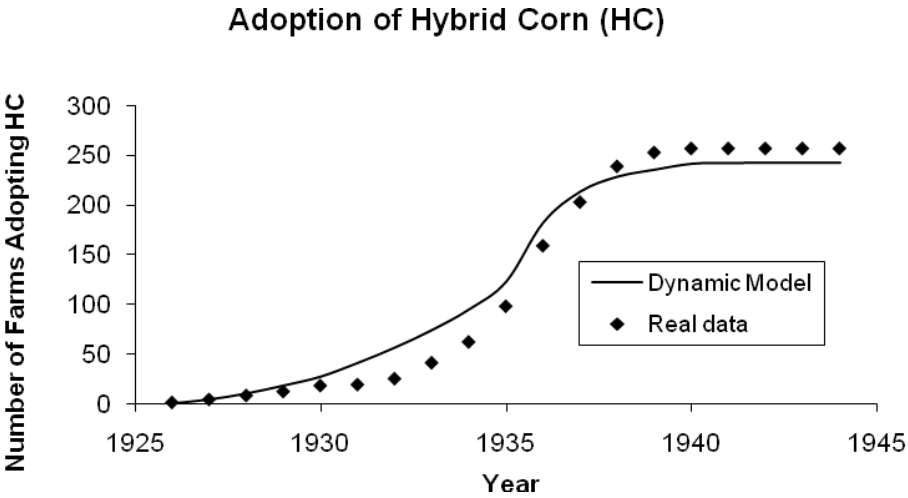

Fig. 1 – Logistic model for Innovation Spread.
Number of adopters per unit of time.

The reader familiar with the mathematical theory of epidemic spread [1] will easily recognize the above model as an epidemic model in a new disguise. It is indeed a model of spread which could be sophisticated in order to take into account other facts related to transmission, like the reprduction rate of ideas spreading.

Let us see how a more sophisticated model is able to describe the dynamics of HC spread. The model assumes two types of farmers, called "susceptible" to the innovation, denoted S_1 and S_2, one of them more opinionated than the other. Both susceptible types of farmers are subject to a broadcasting advertizing, and adopt the innovation at a rate λ farmers per time unit through this way. Once adopted the innovation, susceptible farmers passe to a new state, called "infected" by the innovation, denoted I_1 and I_2, depending on the previous states, if S_1 or S_2, respectivelly. In addition to the broadcasted advertizing, farmers could adopt the new meme by a kind of "infectious" contact with the farmers who had already adopted the innovation. This occured at rates β_1 and β_2 potentially infectious contacts per time unit, depending on the contactant states, if S_1 or S_2, respectivelly. Once the meme was adopted, the farmers were removed from the infectious state to a new, "resistant" state, denoted R_1 and R_2, from the states I_1 and I_2, respectively, with rates γ_1 and γ_2. The more opinionated farmers, I_2, influence the more susceptible farmers S_1, through a new contact rate **r**, but are, in turn, susceptible to the innovation by contact with farmers from the class $\mathbf{I_1}$. The model assumes also that the broadcasting advertizing rate λ decreases with time according to a logistic function, $\lambda(t) = 1/(1+\exp[-\kappa t])$ and that the direct contact rates β_i, **i = 1,2**, increased according to another logistic function $\beta_i(t) = 1/(1+\exp[\omega_i t])$. The model's dynamics is described by the following set of ordinary differential equations [2]:

$$
\begin{aligned}
\frac{dS_1}{dt} &= -\lambda(t)S_1(t) - \beta_1(t)S_1(t)I_1(t) - rS_1(t)I_2(t)\theta(I_2(t)-0.2) \\
\frac{dS_2}{dt} &= -\lambda(t)S_2(t) - \beta_2(t)S_2(t)I_1(t) \\
\frac{dI_1}{dt} &= \lambda(t)S_1(t) + \beta_1(t)S_1(t)I_1(t) + rS_1(t)I_2(t)\theta(I_2(t)-0.2) - \gamma_1 I_1(t) \\
\frac{dI_2}{dt} &= \lambda(t)S_2(t) + \beta_2(t)S_2(t)I_1(t) - \gamma_2 I_2(t) \\
\frac{dR_1}{dt} &= \gamma_1 I_1(t) \\
\frac{dR_2}{dt} &= \gamma_2 I_2(t)
\end{aligned}
\tag{4}
$$

The result of the numerical simulation of the model can be seen in figure 2, which demonstrates the good fitting capacity of this model to real data from the Iowa farmers.

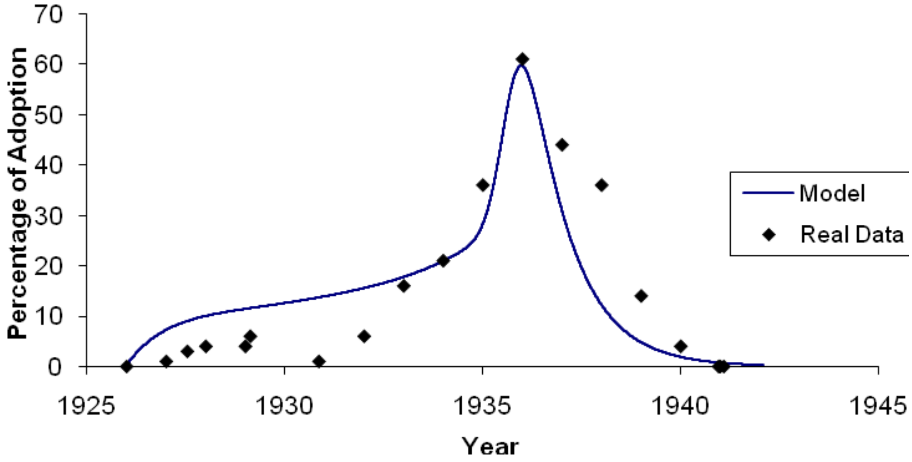

Fig. 2 – Modeling hibrid corn technology diffusion.
Percentage of farms/per year adopting hybrid corn.

We also calculated the basic reproduction ratio of the innovation, the threshold number of "infected" farms, below which the innovation would not spread through the other farms. This is a paralel to the basic reproduction number, $\mathbf{R_0}$, [1], [12], [14], [15] of infections and it is considered the key parameter related to infecious dynamics. For the proposed model, the threshold condition is given by $\lambda=0$, that is, provided the broadcast advertizing is positive the innovation will spread. When this is not the case, that is, the spread is dependent only on the contact between farmers who adopted the new meme and those who are still susceptible, the threshold condition is given by:

$$R_0 = \frac{\beta_1}{\gamma_1} + \beta_2 \frac{r}{\gamma_1 \gamma_2} \quad (5)$$

When the rates λ, β_1 and β_2 are time-dependent (as in this example), this paramater is variable with time and is called 'effective' reproduction number, and is denoted **R**. It starts from zero (when λ is differento from zero) reaching more than 8000 at the peak of the "epidemic" when calculated with the values used in the simulation of the model.

Discussion

Several have been the atempts to provide the new science of memetics with a mathematical framework to model, basically, the spread of memes. The *Journal of Memetics* (http://jom-emit.cfpm.org/all.html), an electronic journal dedicated to memetics, presents a number of articles dealing with the matthematics of memetics. The great majority (if not the totality) of which being essentially na adaptation of population genetics models to memetics. In the paper by Edmonds [8], for instance, a classification of memetics models is presented, with an interesting discussion on the possibilities of modeling memetics. In Kendel and Laland [11], the interaction between memetic and genetic evolution, a phenomenon described as meme-gene co-evolution is discussed. The authors argue that whether cultural evolution occurs purely at the level of the meme, or through meme-gene interaction, is a question to which a body of formal theoretical work already exists that can be readily employed to model empirical data and test theoretical hypotheses. This is cultural evolution and gene-culture co-evolutionary theory, a branch of theoretical population genetics [5], [6], [9]. The authors reject the argument that meaningful differences exist between memetics and these population genetics methods. The goal of this article is to point out the similarities between memetics and cultural evolution and gene-culture co-evolutionary theory, and to illustrate the potential utility of the models to memetics.

The authors conclude that cultural evolution and gene-culture co-evolutionary modelling paradigms can be effectively employed to enhance the quantitative study of memetics. Simple and complex cultural phenomena such as behaviour patterns, belief systems and institutions can be analysed by characteristics of associations between easily definable and quantifiable memes. The quantitative approach can be used to describe meme diffusion dynamics, and make sense of patterns of variation in memes. The methods can also ask why and how human attributes evolved in conjunction with memes, how they continue to evolve, and what is the basis of any stability or maintenance of the trait

In another interesting model Gatherer [10] shows simple computer simulations of the interaction of genetic factors and memetic taboos in human homosexuality, are presented. These simulations clearly show that taboos can be important factors in the incidence of homosexuality under conditions of evolutionary equilibrium, for example states produced by heterozygote advantage. However, frequency-dependent taboos, i.e. taboos that are inversely proportional to the incidence of homosexuality, cannot produce the oscillating effect on gene frequencies predicted by Lynch [13]. Effective oscillation is only produced by rapid withdrawal and re-imposition of taboos in a nonfrequency-dependent manner, and only under conditions where the equilibrium incidence of homosexuality is maintained by heterozygote advantage, or other positive selectional mechanism. Withdrawal and re-imposition of taboo under conditions where homosexuality is subject to negative selection pressure, produce only feeble pulses, and actually assist in the extinction of the trait from the population. Additionally it is shown that frequency-dependent taboos assist in a more rapid achievement of equilibrium levels, without oscillation, under conditions of heterozygote advantage. An attempt is made to relate the simulations to past and contemporary social conditions, concluding that it is impossible to decide which model best applies without accurate determination of realistic values for the parameters in the models. Some suggestions for empirical work of this sort are made.

The above discussion is hence related to the population genetic – like approach to memetics. In an ecological – like approach, that is, how to model memes spreading by dynamical systems, we showed that the classical models applied to describe the dynamics of pathogens can be easily adapted to describe the dynamics of the spreading of memes. We hope that the simple model presented in this paper can represent the seed for what we see as a fertile soil of investigation in the facinating field of memetics.

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