A simple model for the diffusion of ideas

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Abstract

The primordial goal of this research is to study how the micro-relations between individuals shape (and build) a *society*, using an anthropological view rather than a computer-science view: we are interested in the social and cultural forces behind the aggregations of individuals, and in what degree these forces (the *micro-level*) affect the society (*macro-level*) where these individuals live. In order to get a feeling of what could be done in this direction, our first research question would be: *how is the spread of ideas in a community shaping the society?*; a series of experiments illustrating the diffusion of ideas in different types of social networks are presented.

1 Background and motivation

Our general motivation comes from a simple feeling we have developed with the years, while having the great opportunity of living in different places of the world; this feeling has to do with how different the ways of life and the structures of societies can be in different countries. Even under what we can recognize as a common *Western culture*, the life styles and the values from different societies are clearly very differents. And yet, any two people taken from any of these societies are not very different, individually. So, *where does the difference come from?* What processes shape the societies we live in?

Our belief is that this can be explained by studying the dynamics of interaction between the individuals; these *low-level* interactions are certainly a big part of the explanation about the appearance of societies. We are particularly interested in the following questions:

1. **What are the social and cultural forces behind the aggregation of individuals?**
2. **Is the low-level of the society** *aware* **of the high level?** In oher words: when we choose our friends, do we *think* about what kind of a society we are contribuying

to build? Are the dynamics of the construction of these kind of (friendship) communities something that is *chosen* and, therefore, *changeable*?

3. **How is the spread of ideas shaping the communities?**

These questions are not part of any of the authors' original research program; however, we wanted to take the opportunity offered to us in this **CSSS**05 summer school for exploring the intuitions aforementioned. Specifically, we want to explore in deeper detail point number 3, decomposing it in the following:

1. What are the dynamics of the creation/elimination of ideas?

2. What are the dynamics of the acceptation of an idea in society?

3. (related to the first two questions) Where is it *easier* to diffuse a new idea: in a *dynamic* society (as a university, for example), or in *static* society, where very few ideas are present and discussed?

The rest of the paper is structured as follows: the work done by several researchers in building models of networks are presented in section 2; our particular model (and its implementation in **N**etlogo) is presented in section 3. The exploratory experiments done in this setting are described in section 4, and our conclusions and (abundant) future work is expressed in section 5.

2 Network models of societies and communities

It is easy to note, browsing thru the bibliography of the different fields of research related to complex systems, an augmentation of the papers published in the *networks* area. The main reason behind that is that many real world systems (and possibly *all* of the interesting) can be modeled as networks. A *network* (a synonym of the computer-science concept of *graph*) is a structure where the parts composing a system are repesented as *nodes*, and the relationships between them are *edges* or *vertex* (for more details, we recommend Diestel book ([4]) or any other in graph theory; an extense bibliography is found in http://www.graphtheory.com/ .
The subtle difference between networks and graphs is that we talk about networks when there is an implicit *reason* for the structure to appear; relationships (the edges) in networks appear following a dynamic of construction. For example, we talk about a *biological network* when describing a morphogenesis process (some examples are found in Aldana *et al.* in [1], Sole *et al.* in [10] and, in this **CSSS**05: Balcan, Calcutt and Hohenlohe, [2] and Monte, Min, Sheya and Kitami, [8]): the network describes a particular path taken by nature to form a structure. We call a *chemical network* the different points in space and time followed by a chemical reaction (see an interesting review by Rateb and Monaco for **CSSS**05 [9]); there is a *social network* when the people linked by a particular relationship (friendship, for example!) is represented in a graph. As mentioned by Holden, Sanjana and Seiferle-Valencia [6], research on networks by different domain scientists (mathematicians and physicists mainly) have shown that many of these networks share certain kinds of features:

- Many of them are *small-world*, a property that can be described by saying that the distance between nodes (the number of vertices needed to take for going from one node to another) increases logarithmically as a function of the total number of edges. This was first reported by Milgram in a classic paper [7].

- There is a small number of nodes very densely related to the others, and a huge number that is very loosely related. That is translated, in a distribution graph, by a right-skewed curve; it is also represented by a power-law equation [3, 11].

- The network is very clustered (also called *tight-clustered*) [11]: if node **A** is neighbour of node **B**, and **A** is neighbour of **C**, then there is a high probability for **A** to be neighbour of **C**. This is similar to a *probabilistic transitivity property* for networks.

Watts and Strogatz showed ([12]) that these properties applied indeed to social networks[1]. They were mainly concerned with the small-world property, demonstrating how pervasive it is to social networks [6]; well-known examples are the network of actors who have been in a film together, or the network of researchers in a particular research area (*networks*, for example?) However, their primary concern wasn't about *social* networks: it was with *any kind* of networks. For instance, they also showed how the same properties applied to power grids, desease propagation, and the neural network of a worm [6]. They included in their work an algorithm for building a small-world network; see [12] for details.
However, it is our understanding that research work in networks is much more useful for other researchers when the focus is well-defined in a specific domain. In this case, even if social networks are often small-world, the algorithm seems ill-conceived for representing their growth, as some of its assumptions do not apply to human communities (see [6, p.2] for details); other researchers, as Girvan and Newman (in [5], for example) focus on a much more *anthropological* concept, such as the idea of a **community**. Communities are sub-sets of vertices within which vertex-vertex connections are dense, but within which connections are less dense (cited in [5]). It is easy to see how now these communities can represent groups of people, linked by common interests, backgrounds, activities, or any other feature. Girvan *et al.* presented an algorithm to build communities out of random networks, and they showed how the topological results from their algorithm matched the real-world descriptions of social networks [5]. This is an interesting result that models the origin of communities in social networks; but we believe, as the researchers in [6] did too, that the most interesting questions, *anthropological* questions, can not be adressed in a *graph-theory* angle. For example, what cultural forces drive the formation and the solidification of communities? What kind of *high-level* construction (*society*) are these communities achieving? Are the individuals joining a community *aware* of the consequences of their choices? How are the diffusion of ideas in these communities shaping the high-level construct? We believe that by studying the dynamics of the diffusion of ideas in such societies we can hope to find answers to these interesting questions. So our goal is to study the flow of ideas in social networks, which is a relatively new research area. Our first baby steps

[1]We adopt here a straightforward definition of social networks: these are the networks where nodes are human beings, and edges are some kind of social relationship between them-like friendship, for instance-

are shown in this document; the model we implemented and used, and the experiments we designed and run, are described now.

3 Our model

We implemented a simulation of a *society* (a group of individuals) in **N**etlogo, in a Mac OSX environment. The choice of such a tool was motivated by 2 points: (1) we wanted to try and *get our hands dirty* in a new development environment. **R**ePast seemed also adequate but the feeling we had is that in **N**etlogo the development would be faster; and (2) the easy-to-program structure that **N**etlogo has makes it a better choice for a exploratory analysis of an idea.

3.1 An individual, its ideas and its friends

The model we implemented consists of a network of individuals, implementing a local exchange of ideas with its ”*friends*”. Each individual has a number of ”*ideas*”, each of which has a ”*weight*”, representing the preference of the individual for that idea (see Fig. 1).

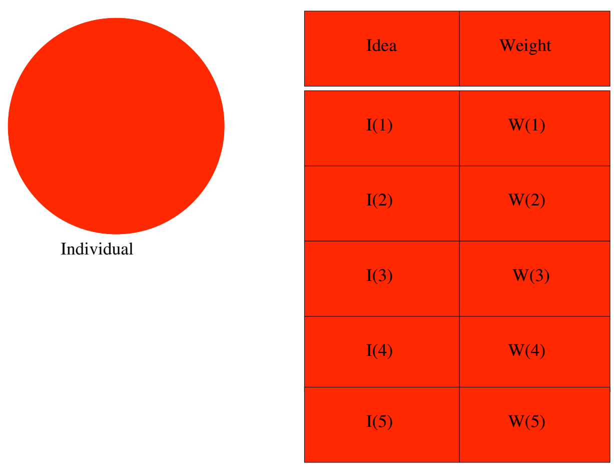


Figure 1: Individual, ideas, and weights

How an individual chooses its friends, and the specifics of the definition of the ideas (how many there are, how are the preferences of an idea in an individual specified and modified) are defined next.

For this specific implementation, each individual has 5 ideas; the ideas are represented by numbers in the range $[1, 15.000]$, and an idea has minimum weight 0 (the individual does not trust this idea) and a maximum weight of 1 (the individual completely trusts this idea). At its *birth*, an individual has 5 ideas taken randomly from the

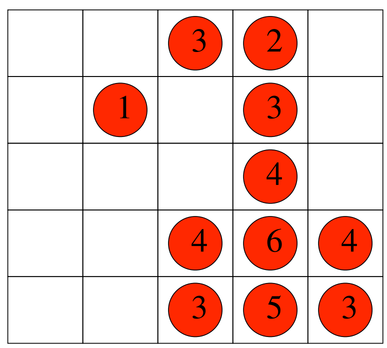
pool, with random weights.
The individuals live in a lattice size 256x256; each cell of the lattice can be occupied by at most 1 individual. As each cell has 8 neighbours, so will an individual. The initial position of each individual is determined by 1 of 3 possible algorithms (given as options in the environment):

1. **Random attachment**: an individual, when entering the lattice, takes a random spot close to a random individual.

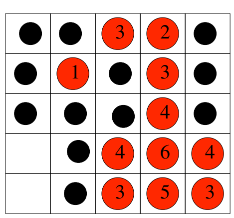
2. **Attachment to the most popular**: the individual entering the lattice takes a free spot beside the *most* popular individual (with a free spot at its side).

3. **Attachment to the less popular**: the individual entering the lattice takes a free spot beside the *less* popular individual (with a free spot at its side).

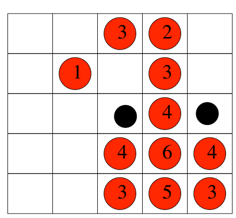
These cases are illustrated in Fig. 2; a specific initial positions for 11 individuals in a 5x5 lattice is shown (Fig. 2(a)). On each agent, the number of neighbours is specified. The choices for an individual entering at this moment in time are shown as black dots for each case (Fig. 2(b,c, and d)).



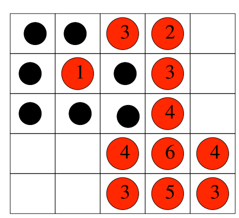
(a) Initial lattice positions



(b) **Random attach**



(c) **Most pop attach**



(d) **Less pop attach**

Figure 2: Attachment types

Each individual is, initially, friends with its neighbours. The relation of *friendship* is defined by an edge linking 2 individuals. This edge has a *strenght*, taking values in $[0, 1]$ (0 is *no friendship*, 1 is *maximum friendship*). The initial friendship strengths of the lattice shown in Fig. 2 would be as represented in Fig. 3.

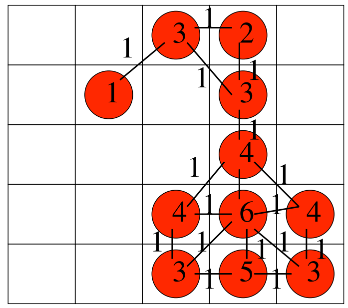


Figure 3: Initial friendship

3.2 Exchange of ideas

The *exchange of ideas* is performed by each individual; **I** exchanges ideas with its neighbours following these steps:

1. For each of **I**'s friends, *ask*: *what are your ideas?* (Fig. 4) In Fig. 4, **I** has 4

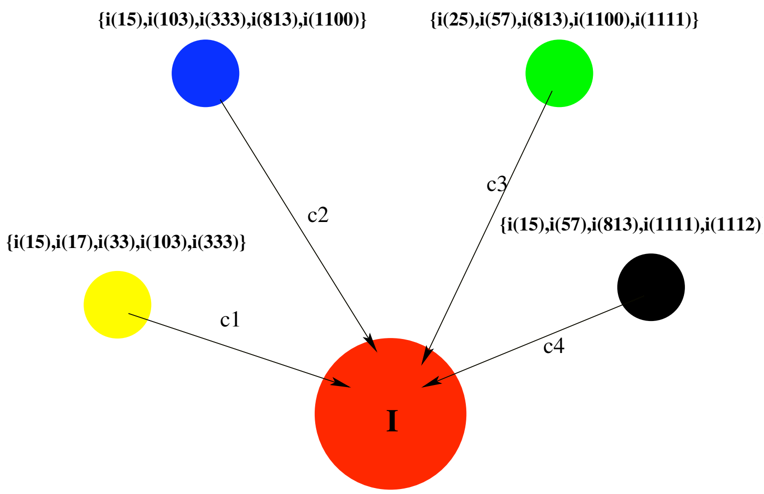


Figure 4: *What do you believe in?*

   neighbours, linked with weights c_1, c_2, c_3 and c_4, respectively. Each neighbour *answers* with a list of its ideas to **I**; it is important to note that **I** does not know the amount confidence each of its neighbours has on its ideas (weights on Fig. 1).

2. Individual **I** builds a list with all the ideas received, weighted by the **friendship strength** with each neighbour (Table. 1)

idea	approval	weight	idea	approval	weight
$i(15)$	3	$c_1 + c_2 + c_4$	$i(103)$	2	$c_1 + c_2$
$i(17)$	1	c_1	$i(333)$	2	$c_1 + c_2$
$i(25)$	1	c_3	$i(813)$	3	$c_2 + c_3 + c_4$
$i(33)$	1	c_1	$i(1100)$	2	$c_2 + c_3$
$i(57)$	2	$c_3 + c_4$	$i(1111)$	2	$c_2 + c_3$
$i(1102)$	2	$c_2 + c_3$			

Table 1: Understanding of **I** about its neighbours' beliefs

   (The *approval* of an idea is the number of neighbours that believe in the idea)

3. Based on these opinions, **I** examines each of his neighbours opinions and decides whether to accept them or not. When accepting any of them, **I** has to "forget"

one of his ideas, as he can only keep 5 ideas (see specifics in page 4). The step-by-step process of accepting/rejecting a particular new idea is exemplified next, taking as an exemple idea $i(15)$, with its corresponding weight $= c_1 + c_2 + c_4$ and approval = 3 (Table 1) :

(a) **I** takes a random idea from his beliefs (for example, i_1, confidence w_1, as in Fig. 1)

(b) The decision on whether to keep $i(15)$ or not (and therefore losing i_1) is taken probabilistically based on the approval of the idea: a dice is thrown weighted by the approval divided by the total number of ideas (in the case of $i(15)$, the bias would be $3/4$)

(c) If $i(15)$ is accepted, its initial weigth is calculated as the ratio between its weight (as in Table 1) and the total weights of the ideas (Eq. 1)

$$\mathcal{IW}(i(15)) = \frac{c_1 + c_2 + c_4}{c_1 + c_2 + c_3 + c_4} \tag{1}$$

The same process is repeated for each new idea in Table 1

3.3 Movement, new friends, old friends

Each moment in time, each individual moves around the lattice randomly; one of its steps consists on moving to a neighbour cell that is free. If there is none, he will not move.
If he moves, and following the definition of friendship of subsection 3.1, he becomes friends with its new neighbours, with a friendship strenght equal to 1 (maximum) In Fig. 5, the *red* individual moves close to the other individuals, and then becomes friend with them.

Figure 5: Making new friends

At the same time, as an individual gets farther away from its friends, their ideas become somewhat *less important* to him, even if they stay friends. We model this fact by implementing a decay in the friendship strength that follows a simple radiocative decay equation (cf. Eq. 2).

$$A = A_0 * e^{-\lambda * t} \tag{2}$$

This equation expresses the decay of active emission from a radioactive material after a time t; λ, the *decay constant*, is defined as $\lambda = \frac{ln(2)}{\mathcal{T}}$, $\mathcal{T}$ being the length of time required for the emission to lose half of its strength (i.e., $A = \frac{A_0}{2}$)[2] Our specific implementation deals with *distance*, not with time, so it is expressed in the slightly different way of Eq. 3, where f_t means *friendship at time* t and d is the distance between the two individuals:

$$f_{t+1} = \begin{cases} 1 & \text{,if } d = 1 \\ f_t * e^{-0.07 * d} & \text{,otherwise} \end{cases} \tag{3}$$

The expression of Eq. 3 means that the strength of a friendship will decay to 0.5 when an individual is at a distance of 10 cells of his friend. The general expression, where the friendship will decay to a value of 0.5 when at a distance of dh cells, is (Eq. 4):

$$f_{t+1} = \begin{cases} 1 & \text{,if } d = 1 \\ f_t * e^{-\frac{ln(2)}{dh} * d} & \text{,otherwise} \end{cases} \tag{4}$$

dh is a parameter of the simulation.
Our implementation included a *friendship deletion policy*: if the strength of a relationship is lower than fd, then the strength is set to 0. fd is a parameter of the simulation.

[2]For more information see, for example, http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/halfli2.html

An example of the dynamic of change of weights is show in Fig. 6, where the *red* individual walks away from its friends. The new values of the strengths are shown. Note

Figure 6: Losing friends

how the strength of the friendship is different when the distance is smaller (2 in the case of the straight line, $2\sqrt{2}$ for the diagonals.)

4 Experiments and Results

We built the agent-based model corresponding to our concepts of how the ideas are diffused in different kinds of social networks. Our model allow an easy and intuitive graphical viewing of the world, the agents, the network topology (the friendship relations) and the acceptance of the ideas over the society during the simulation.
Very few results have been obtained; we actually spent most of the time having a feeling of what was really going on, paying attention to possible *bugs* and making sure that our work hypothesis were sound. We believe that our actual research will begin (paradoxically!) in the points outlined in future work (section 5).
We run the simulation with 2 questions in mind:

1. What is the *stabilization* point for the ideas in our society? Let's say we have n individuals living in the lattice, each one of them holding 5 random ideas: how many ideas survive after t time steps, how many survive assymptotically?

2. Once the ideas are stabilized in the society: what does it take for a new idea to *enter* the society belief system?

4.1 A simple case: no movement

The simplest case with this simulation comes when the individuals do not move around in the lattice; this is the first set of experiments we designed.
For beginning to ask these questions, we monitor the number of ideas accepted by at least 25% of the population. The lattice size is 256x256 , the number of individuals is 100. In all of our simulations, after 500 cycles, between 5 and 6 ideas were accepted by at least 25% of the individuals.
The insertion of new ideas have to be designed in a careful way, taking into account all parameters of the simulation. Our very first experiments in that direction gave us some bizarre results: we injected an idea to 1 individual in the society. This idea was then accepted by *everybody* in the simulation 500 epochs later! Obviously, that doesn't have any statistical or scientific justification, but it is something that we have to elaborate on.

4.2 And now they move!

A more interesting case arises when the individuals are freely moving around the lattice. No clear results were obtained here, so we are not presenting any. A paper is currently being produced for this case.

5 Conclusions and Future work

The relationship between the micro-level dynamics and the macro-level structures in a society were investigated in this paper, taken as a particular example a social network of friendship. A simulation model was built, and extensively tested. No practical results were obtained; rather, we presented here the work achieved during the intense and highly rewarding month in **CSSS**05. The exploration of a new area of research proved to be extremely useful for both of us, and the discussions about this and other subjects inspired us for our research work (at Santa Fe and back at home). We are currently developing the interface and the original ideas of the paper, and hoping to achieve a steady-state in a few weeks; the point reported here is modest in results, but extremely valuable as a starting point.
A comment concerning the implementation: **N**etlogo was a good choice, as it helped us to get ahold of some ideas without much programming; however, we feel that a more strucutred environment (as **R**ePast) would be a better choice for a large development. The migration should be straightforward, given that **R**ePast already implements some graphic utilities. We recommend it, if the programmer happens to master Java.
A whole world of *future work* is present in our head; we present it here as different points:

- Characterize the **kind of networks** obtained in Fig. 2. Which case is a random network, which case is small-world, why? We have an intuition of the kind of networks that we are obtaining, but we would like to related it with the more *classical* algorithms of network construction: in what way are they comparable?

- **Mathematics**: our model is, we believe, pretty simple. But, at the same time, it contains a decent set of parameters that we can vary (number of individuals, size of the lattice, type of attachment, percentage of popularity measured, among others). These two reasons tell us that we should set up an analytical model for describing the dynamics, and we think that this model can help us to decide the set of interactions we want to study. This is a very important step that should be done before going on with any more refinement of the simulation.

- **Percolation**: our model can be seen as a medium that diffuses information, following a particular dynamic. In that sense, we can apply a percolation model to see how it compares with known results.

- **Acceptance of ideas based on different actors (from different communities!)**: the concept of community has not been exploited in our work. But, as Girvan and Newman mentioned [5], it is present in all social networks. An idea that appeared in our discussions in Santa Fe was for an individual to accept a new idea based on the opinions of the individuals coming from communities different from his. This is the equivalent of accepting an idea when it comes from an engineer *and* a doctor: if it is present in different communities of the society, maybe it is a good idea! This angle is very interesting and we want to look into it in detail.

- **Noise**: the algorithm for accepting a new idea assumes that my neighbours ideas are prefectly understood by an individual. But this isn't always true: what happens if the ideas are not well-understood when diffused? How are the dynamics of diffusion of ideas affected?

Acknowledgements

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