Agent-based model of competition in a social structure

Erika Fille Tupas Legara, Anthony Garcia Longjas, and Rene Cabahug Batac

National Institute of Physics, University of the Philippines, Diliman, Quezon City, Philippines 1101

Received: date / Revised version: date

Abstract. Indirect competition emerged from the complex organization of human societies, and knowledge of the existing network topology may aid in developing effective strategies for success. Here, we propose an agent-based model of competition with systems co-existing in a 'small-world' social network. We show that within the range of parameter values obtained from the model and empirical data, the network evolution is highly dependent on $k$, the local parameter describing the density of neighbors in the network. The model applied to language death and competition of telecommunication companies show strong correspondence with empirical data.

PACS. 89.65.-s Social and economic systems - 89.75.Hc Networks and genealogical trees - 89.00.00 Other areas of applied and interdisciplinary physics

1 Introduction

Competition drives intelligent beings to develop strategies for better adaptation and survival. Ecological competition for resources or space, for example, may drive a species to extinction in the absence of an adaptive mechanism. While ecological competition is in itself interesting, other forms of competition have sprung up from the complex organization of human societies. Such competition dynamics are called indirect competition [1] in the sense that they have no material resource and involves nonliving entities that thrive out of human interactions. Indirect competition is an interesting case for study given the wide scope of its possible applications. In analogy to direct competition, these competition dynamics still have the resource and spatial aspects, although in a slightly different sense: resource refers to the individuals, and space represents their actual distribution in a social network where they belong. Examples of such entities include language [2]; word-of-mouth businesses [3]; ethnic violence [4]; and utilities like...
Internet service providers and telecommunication companies [5].

In studying competition dynamics of this nature, the underlying network structure of human societies must be accounted for. Real human networks are not uniform and perfectly structured or random, but are in fact midway between these two extremes with very high clustering coefficients and short characteristic path lengths [6]. The number of friends in an acquaintanceship network is not the same for all individuals and it is therefore not straightforward to assume that agents in the real world will behave similarly under the same circumstances. This is so because earlier works prove that decision-making in humans is most affected by the local neighbourhood of friends or cliques [7,8,9], and the dynamics of connection with friends can catalyze competition and diversity in business and society [10].

Competition in business is an interesting example for studying indirect competition because it employs advertising as a strategy to obtain a larger market share. In fact, the advertising industry is projected to spend USD 653.9 billion worldwide for the year 2008 [11]. This staggering amount is a testament to the efforts of big companies to influence the public to purchase their products and services. Indeed, in an ideal free-market economy, it can be argued that advertising is even more intensified in the presence of a competitor. But in the context of a social structure, one is left to wonder whether the traditional advertising schemes that attract random individuals globally are as effective as those that exploit the network topology of the population. Using a highly-clustered network in an agent-based model of competition, we demonstrate that schemes directed at local cliques within the network are more successful at gaining a larger share of the population than those intended for users randomly at a global scale (e.g. television commercials, print ads, etc.).

The paper is organized as follows. The agent-based model (ABM) used is described in detail in section 2. To test the general validity of the model, simulation results are superimposed with empirical data for both language and business competitions in section 3. A conclusion of the important findings is given in section 4.

2 Agent-based simulations

The motivation for the use of ABM is the difficulty in using differential equations, in the limit of large populations with highly complex interactions, to capture emergent properties of social systems. These essential features, on the other hand, are readily observed in variants of ABM [12]. In fact, many works using ABM have dealt on modeling a variety of social phenomena such as cooperation [13], information/epidemic propagation [14,15,16], evolution of social structures [9,17] and other forms of social interaction [18].

In this work, we construct a Watts-Strogatz (WS) small-world network of agents to model indirect competition. The network of $N$ agents is initialized as a regular network with $k_{WS} = 14$. Rewiring is then implemented with reconnection probability $\rho_{WS} = 0.01$. No two nodes can have more than one edge connecting them, and no node
is connected to itself. Rewiring the network allows it to evolve from a completely ordered one into a small-world network representing a social network, where our model of competition is simulated. The nodes in the resulting social network correspond to the agents in the system under study.

Upon the construction of the network, a fraction of $N$ is arbitrarily assigned to be into one of the two competing groups $X$ and $Y$. Agent interaction is simulated and limited only to those they are socially connected with. Suppose that for one time step, an agent from $Y$ decides to transfer to $X$. The transition probability for this happening is given by

$$P_{yx} = k_x^\alpha s_x^\gamma$$  \hspace{1cm} (1)$$

where $k_x$ is the number of neighbors an agent has who belong to group $X$, and $s_x$, the perceived status of $X$, a parameter that quantifies “the social and economic opportunities afforded” to members of $X$ [2]. The parameters $\alpha$ and $\gamma$ are scaling exponents. Using a transition probability in the form of Eq. (1) in effect categorizes the factors that may affect people’s choices into two general types: a global factor in $s$ that is external to the network architecture, and a local factor in $k$ that accounts for the prevailing network conditions. The probability to change from $X$ to $Y$ is constructed in the same manner. These transition probabilities govern the evolution of the two competing groups.

Fig. 1. Network evolution. Clustering of agents belonging to the same community becomes apparent as $t$ increases. Green and blue nodes correspond to agents belonging to $X$ and $Y$, respectively; red nodes denote those that are initially unassigned. Edges indicate friendships between two agents.

3 Results

3.1 Network topology and evolution

For purposes of illustration, we present in Figure 1 a network of $N = 100$ agents, its initial distribution and evo-
olution in time. The node colors represent different population groups and the edges, social connections.

Clustering of agents in the same community becomes apparent as time increases exhibiting a bandwagon effect known as allelomimesis. Allelomimesis is inferred as the way of an agent to adapt by mimicry of the behavior of the majority of its neighbors resulting to clustering behavior [8,19]. Our model captures the clustering observed in real-world networks.

The network structure in Fig 1 demonstrates the effect of local friendships on the dynamics of the network. Rather than being randomly distributed throughout the entire network, groups belonging to X and Y tend to be clustered and are thus spatially distinct from each other. This observation supports the Schelling socio-economic model of segregation and is observed in human societies [20,21].

### 3.2 Dynamics of language death

The rate of decrease in the number of languages spoken is alarmingly high, and it is even predicted that 90 percent of the world’s spoken languages will vanish by the end of the century [22]. In an earlier work, Abrams and Strogatz proposed a model of language death based on a coupled differential equation which accounts for the perceived status of a given language. The model showed good correspondence with empirical data for Welsh, a native language in Wales. The decay in the number of Welsh speakers is attributed to the rise of an alternative language, and thus represents an example of an indirect competition [2].

![Fig. 2. Modeling the language death of Welsh in all of Wales.](image)

Welsh speakers from historical data (filled) fitted with simulation results (empty). Simulations utilized online ‘small-world’ results with mean characteristic path length in the range 5 - 7 [23]. Simulation parameters are \( N = 5000, k_{WS} = 14, \rho_{WS} = 0.01 \); \( \alpha = 0.9, \gamma = 0.2, s_{Welsh} = 0.1 \).

We applied our competition model to investigate the evolution of a minority language using Welsh speakers data from historical accounts spanning 1900 - 1980. Figure 2 compares our simulation results and empirical data. Our indirect competition ABM of language endangerment accurately describes the evolution of the minority language. It is evident that as time increases, the model forecasts that the number of Welsh speakers would further decrease.

It should be noted that indirect competition of language in a society is a continuous process, which involves very little strategy on the part of the language users themselves. The use of a language is primarily dictated by the prevailing social and economic conditions, and rarely do we see groups lobbying for or against a language or another. In the next section, a more active arena of social
competition is investigated, and strategies for “winning” in such competition dynamics are proposed.

### 3.3 Business competition

As noted before, business competition involves advertising as a strategy. There is an active and continuous effort in the part of the companies to win over possible consumers. This is done by highlighting the advantages of their products and services over those of their competitors, or, occasionally, destroying the reputation of the rival companies and their products.

We study two companies in the Philippines that are involved in the telecommunication business. Mobile phone companies in the Philippines have attracted nearly 50 million users in less than a decade, generating more than USD 1 billion in annual sales and revenues [24]. The dynamics of the two biggest players in the field, Smart Communications (SC) and Globe Telecommunications (GT) is therefore interesting not only in the economic perspective but as another example of indirect competition.

Using the data provided by the companies on their number of subscribers [25] and the Philippine population data [26], agent based results are superimposed for the fraction of SC and GT subscribers and the unsubscribed population in Figure 3. Note that there are three different population groups being considered taking into account the unsubscribed individuals. Nevertheless, the competition is still exclusive between the two companies since the perceived status for not subscribing in any of the two services is negligible (i.e. community of non-subscribers do not promote unsupscription).

The values for the scaling parameters \( \alpha \) and \( \gamma \) are 0.99 and 0.10, respectively. The parameters \( s_{SC} \) (perceived status of SC) and \( s_{GT} \) (perceived status of GT) are 0.502 and 0.498, respectively. These values were obtained through normalization of the actual market shares of the telecommunication companies. Between the years 2000 and 2007, model results follow the increasing trend in number of SC and GT subscribers, with SC enjoying a slightly higher percentage of users. The unsubscribed population decreased correspondingly.

Our obtained values for \( \alpha \) and \( \gamma \) reveal heavy dependence on \( k \) especially when the perceived status of the two competing groups are approximately the same. In a real-world setting, this translates to the fact that individ-
uuals, in decision-making, tend to prioritize social ties over possible benefits. This is more evident in the choice of telecommunication subscription among cliques; a person may choose a more costly subscription with a company that offers less benefits if it is a majority in his/her local neighbourhood.

This result hints to a possibility for better advertising schemes for competing business enterprises. Instead of the traditional forms of advertising, which attract the public with little regard for their actual social ties, companies may opt to target social circles within the network. Among the more immediate advantages of doing such are: (1) faster information dissemination and (2) lower dissociation probability due to strong loyalty to friends. Ultimately, these translate to a larger share of users in the population, which is “winning” in the indirect competition.

4 Conclusion

The competition model presented here accurately described the evolution of a minority language and business competitions - both considered as forms of indirect competition. We have shown that the dynamics of the population of communities depends on: (1) the perceived status of the community and (2) the degree of connection of individual agents. Introducing the latter in our model sufficiently accounted for the important role of social interactions in correctly describing the dynamics of such emergent competition. Finally, we suggest that our model of indirect competition in a social network is general and straightforward and can be applied to other forms of competing community structures that already exist.

Acknowledgements

We would like to thank Christopher Monterola and Johnrob Bantang for their invaluable insights and useful discussions.

References

1. P. J. Darlington, Jr., PNAS 69, (1972) 3151-3155.
2. D.M. Abrams, S.H. Strogatz, Nature 424, (2003) 900.
3. E.F. Legara, C. Monterola, D.E. Juanico, M. Litong-Palima, C. Saloma, Physica A 387, (2008) 4889-4895.
4. M. Lim, R. Metzler, Y. Bar-Yam, Science 317, (2007) 1540-1544.
5. O. Foros, B. Hansen, Information Economics and Policy 13, (2001) 411-425.
6. D.J. Watts, S.H. Strogatz, Nature 393, (1998) 409410.
7. Y. Moreno, M. Nekovee, A. Vespignani, Phys. Rev. E. 69, (2004) 055101.
8. D.E. Juanico, C. Monterola, C. Saloma, Phys. Rev. E 71, (2005) 041905.
9. D. J. Watts, P.S. Dodds, M.E.J. Newman, Science 296, (2002) 1302 - 1305.
10. D. Pennock, G. W. Flake, S. Lawrence, E. J. Glover, and C. L. Giles, PNAS 99, (2002) 5207-5211.
11. R. Coen, Insider’s Report Universal McCann (2007).
12. E. Bonabeau, PNAS 99, (2002) 7280-7287.
13. N.M. Gotts, J.G. Polhill, A.N.R. Law, Artificial Intelligence Review 19 (2003), 3-92.
14. P. G. Lind, L. R. da Silva, J. S. Andrade Jr., H. J. Herrmann, EPL 78 (2007), 68005.
15. A. Lloyd, R. May, Science 292 (2001), 1316 - 1317.
16. V. Colizza, A. Barrat, M. Barthelemy, A. Vespignani, PNAS 103 (2006), 2015-2020.
17. E. Ravasz, A. L. Barabasi, Phys Rev E 67, (2003), 026112.
18. M.C. Gonzalez, P.G. Lind, H.J. Herrmann, Eur. Phys. J. B 49 (2006), 371-376.
19. D.E. Juanico, C. Monterola, C. Saloma, Physica A 320, (2003) 590-600.
20. T.C. Schelling, J Math Sociol 1, (1971) 143186.
21. T.C. Schelling, Micromotives and Macrobehavior (Norton, New York 1978).
22. M. Krauss, Language 68, (1992) 410.
23. P. S. Dodds, R. Muhamad, D. J. Watts, Science 301, (2003) 827 - 829.
24. Statistics provided by: http://www.manilatimes.net/national/2007/feb/04/yehey/images/front.pdf
25. Number of subscribers are provided by: http://portal.ntc.gov.ph
26. Population data are provided by: http://www.census.gov.ph