A Multi-Agent Model of Individual Cognitive Structures and Collaboration in Sciences

Bulent Ozel

ozel@uji.es
Universitat Jaume I, Department of Economy, Castellon De La Plana (Spain)

Motivation

This research takes a multi agent perspective while simulating knowledge diffusion mechanism in science. Multi agent systems are systems that are composed of a large number of autonomous agents that are capable of interacting with each other. The autonomous agents are not controlled by a central mechanism, instead, their decision taking logics are part of their actions and they are decentralized, hence, they are able to make decisions in order to accomplish individual tasks (Wooldridge, 2009). In this research, a scientist who is situated within a co-authorship network is considered as an individual autonomous agent. Her decision process at picking another scientist to co-author a paper and outcome of such an interaction builds up our multi-agent system.

In a science network, if two scientists work on the same paper, then they are considered connected. The social interaction linkage between them is a possible channel for knowledge diffusion. In our model, each author is considered as an agent that is capable of working with other authors, choosing whom to work with and what subject to work on. In order to set-up initial environment of our multi-agent system we need to identify initial co-authorship network, as well as, we need to represent knowledge space of each individual author in the network. In order to capture a representation of an individual's expertise a set of keywords, which is driven from publications of the author is used to form the node set of the semantic network of that very individual. The semantic relations, namely the links, in between the keywords in the set are established by their co-occurrence on a published article.

There are a number of challenges at designing interaction and evolution of such multi agent system. The challenges are (i) being able to incorporate a dynamic social network perspective while modelling interactions in between agents, (ii) designing, simulating and examining various knowledge creation and diffusion mechanisms as the outcomes of agent-agent interactions.

The first challenge addresses a problem within multi-agent modelling research area. Computational simulation of social systems falls short at covering dense and multitude interactions in between actors. Majority of agent-agent interactions are implicitly and limitedly modelled via agent-agent interactions using environmental variables. This limitation is partly due to complexities at agent-agent interactions and mainly due to lack of empirically validated interaction mechanisms. In this work, we borrow and adopt models from social network literature. More specifically, we examine co-authorship networks and empirically validated interaction models within the field.

In the second challenge, we take a socio-cognitive approach. We model and exploit cognitive structure of each agent both at the incentives of individuals to select other agents to collaborate and at modelling the outcome of resulting interactions. Namely, agents purposefully interact to create and transfer new knowledge.

In addition to challenges mentioned above there are several implementation challenges to be addressed for the simulation model. First of all, not all agents in the population interact with each other at each run and preferences of interaction cannot be uniformly random. In the model, those ones who decide to collaborate compute the set of candidate collaborators autonomously. An agent's current knowledge space, and his/her ego network are taken into consideration at incentives to collaborate. For instance, literature suggests that repetition of joint collaborations follows a power law distribution (Morris & Goldstein, 2007) mimicking power law distribution of individual publication productivity. Likewise, propensity to collaborate with collaborator of an existing co-author is incorporated adopting transitivity property of social ties (Wellman, 1988). Another empirically validated model of social tie formation mechanism that is adopted is "preferential attachment". It is known that in a complex social network probability of a node to have a new connection is proportional to the connections it already has (Barabasi, 2002). At each round of the simulation each agent independently determines a candidate set of collaborators. This candidate set is formed employing above-mentioned mechanisms.

A second implementation challenge is how to incorporate knowledge of individual agents. Dynamic social network mechanism does not take actual knowledge space of individual into consideration. In other words, knowledge space of individuals does not play a direct role on the interactions. Besides, while social interaction mechanisms hint whom to pick to collaborate it does not explain outcome of interactions. It is necessary to come up with empirically validated and sound models to represent what knowledge will be exchanged as the outcome of such social interactions.

Literature suggests that there are two competing social mechanisms, which may help to consider cognitive structure of individuals on the preferences of collaborators. They are 'cognitive distinctiveness' and 'cognitive similarity'. Cognitive distinctiveness or cognitive similarity of two agents is measured by comparing their knowledge bases. For a pair of agents when the distinctiveness is high then there are more possibilities for them to learn from each other. If their knowledge bases overlaps widely, the knowledge they can get from each other is limited (Carley, 1991). However, it is known that people, in some cases, tend to interact with people they are similar to; a tendency, which is known as homophily (McPherson et al., 2001). The experiments are devised to observe impact of these two competing models.

Implementation

As we have mentioned above, each author is represented as an agent. Each agent has its own individual memory, where its knowledge base and its co-authorship history is kept and updated throughout the simulation. Knowledge base of an agent is formed by set of keywords based on agent's publication records. This set of keywords is interrelated to each other. It is represented by a symmetric matrix. The matrix is a representation of cognitive structure of an agent. The entries of the matrix encode co-occurrence frequency of respective keywords. Co-authorship memory of an agent is a set of authors with whom the agent worked with on a publication.

Set of all the keywords that are gathered from all of the publications is represented as a weighted graph. If two keywords belong to the same publication, then they have a connection and weight of the connection is the number of the times they are used together. When entire set of publications for all agents is considered, then this graph is the cognitive structure of the entire network and it will be represented as an environmental component in the simulation.

It is certain that real agents learn from each other via collaboration, but this is not the only way of learning new things. They also learn from their readings, the workshops they attend and many other resources, etc. In order to represent all such various source of knowledge accumulation by agents, knowledge injection method is used. At each simulation time point, which is set as a year, a set of new keywords is added to the cognitive structure of entire population. A probabilistic model is adopted to update cognitive structures after injection of new keywords to the set. Betweenness centrality of existing keywords is used. The higher betweenness of a keyword, the higher chance it receives a new link.

Initial Findings and Future Work

Results from our initial experiments hint that in scenarios where agents are inclined to collaborate with cognitively dissimilar agents, then resulting collaboration structure rather mimics co-authorship relations seen within a research center. On the other hand, when cognitive similarity leads the incentives to pick a collaborator, then resulting co-authorship rather mimics network structures observed within domain of a journal in a field.

A large set of experiments is to be conducted to fully verify and validate our initial results, as well as, to discuss challenges addressed above.

There are a number of additional implementation challenges, which will be addressed and attempted as part of this ongoing research. They are (i) how to model when and in what circumstances multiple co-authorship occurs; (ii) at each run, not only new knowledge pieces but also new agents will be injected to the simulation. Knowledge base of those new agents will be composed of partially by a subset of keywords that is already in the current set and partially by new keywords that is not in the set. This approach will mimic arrival of new scientists in a field.

Bibliography

Barabasi, A. L., H. Jeong, Z. Neda, E. Ravasz, A. Schubert, & T. Vicsek. (2002). Evolution of the social network of scientific collaborations. *Physica A: Statistical Mechanics and its Applications 311*(3-4), 590–614.

Carley, K. (1991). A theory of group stability. *American Sociological Review 56*, 331–354.

McPherson, M., Smith-Lovin, L. & Cook, J. M. (2001). Birds of a Feather: Homophily in Social Networks, *Annual Review of Sociology 27*, 415-444.

Morris, S.A., & Goldstein, M.L. (2007). Manifestation of research teams in journal literature: a growth model of papers, authors, collaboration, coauthorship, weak ties, and Lotka's law. *JASIST*, *58*(12), 1764-1782.

Wellman, B. (1988). *Social Structures a Network Approach*, 19–61. Cambridge University Press.

Wooldridge, M. (2009). *Introduction to Multi-agent Systems*. John Wiley & Sons.