Agent-Based Simulation and Cooperation in Business Organizational Settings

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***Abstract*—The object of this paper is to use Agent-Based Simulation (ABS) to study the effects of cooperation in business organizational settings. To model the functioning of a business organization we have used an Enterprise Engineering approach named Design & Engineering Methodology for Organizations (DEMO). DEMO is based on the Ψ-theory which has the overall goal to extract the essence of an organization from its actual appearance. This theory assumes that an organization is a system of actors and incorporates four axioms. The operation axiom tells us that the implementation independent essence of an organization consists of actor roles and that the acts performed by the actor roles can be divided into two kinds: production acts and coordination acts. Another important axiom is the transaction axiom which states that coordination acts are performed as steps in universal patterns. Based on these assumptions and Game Theory principles of cooperation, a simple ABS was develop focused on studying the conditions that allow cooperation to emerge. By understanding these conditions, appropriate actions can be taken to foster the development of cooperation in such settings.**

***Keywords*-Agent-Based Simulation; Cooperation; Enterprise Engineering; Game Theory.**

I. Introduction

There is an increasing level of dynamics and uncertainty characterizing organizations and their environments. Consequently, contemporary organizational thinking has evolved to embrace paradigms supported by Complexity Theory and its principles. Complexity-based paradigms replace deterministic perspectives of the internal and external workings of organizations by perspectives based on emergence, self- organization and evolution [1]. In these paradigms, organizations are regarded as Complex Adaptive Systems that emerge from the interactions among human and non-human agents.

Complexity Theory involves the study of many actors and their interactions. The actors may be atoms, fish, people, organizations, or nations. Their interactions may consist of attraction, combat, mating, communication, trade, partnership, or rivalry. One of the central topics regarding interaction between self-interested agents is cooperation. Cooperation is crucial for societies and organizations, since it allows the creation of common goods that no single individual could establish alone. However, this situation itself presents a dilemma, because as the creation of these goods requires an individual effort and the result is shared by everyone, there is the temptation to make an individual contribution as little as possible and receive as much of the result as one can. The problem of how can cooperation emerge in a organization of self-interested individuals is one of the central questions addressed by Game Theory, Political Science and Behavioural and Evolutionary Economics.

The study of large number of actors with changing patterns of interaction often gets too difficult for a mathematical solution, therefore other type of solutions need to be used. A primary research tool of Complexity Theory is computer simulation. The basic underlying function of this tool is to specify how the agents interact, and then observe properties that occur at the level of the whole organization.

The simulation of agents and their interactions is known as Agent-Based Simulation (ABS). The goal of ABS is to enrich our understanding of fundamental processes that may appear in a variety of applications. This is the assumptions underlying the proposal described in this paper. To represent the functioning of an organization DEMO's Ψ-theory [2], [3], [4] was used. This theory combines concepts from the Language/Action Perspective (LAP) [5] and Speech Act Theory [6]. The Ψ-theory explains how and why people cooperate and communicate. It postulates that the operation of an organization can be expressed by a specification of the commitments that the organizational subjects enter into and comply with [7]. Based on this theory and concepts developed in Game Theory, this paper proposes an ABS with an underlying conceptual model that allows to experiment and analyse the different patterns that emerge when organizational subjects use different kind of strategies to handle commitments to produce organizational output.

We start by describing (Section 2) two of the most influential games studied as the best representation of the problem of social cooperation. These are respectively the Prisoner's Dilemma and the Stag Hunt. Also, in this section, some conclusions are drawn about what are the central concepts and conditions that promote cooperation to emerge. Next (Section 3), we explain and analyse how organizations are modelled using DEMO's Ψ-theory. Based on what was presented in Section 2 and 3, a very simple case study is presented (Section 4). Also, in this section, some of the potentials and limitations of the presented solution are discussed. Finally, (Section 5) conclusions are drawn pointing to the future scope for development that lies ahead on this vast and interesting field.

II. Cooperation

The evolution of cooperation has been largely studied in the research field of Game Theory [8], [9]. Game Theory studies what happens when self-interested agents interact. Self-interested agents are agents that have their own beliefs, preferences and actions as opposed to teams where some of these characteristics are shared among the group [10]. The assumption of self-interested therefore allows an examination of the difficult case in which cooperation is not completely based upon the concern for others or upon the welfare of the group as a whole. So, the assumption of self-interest is really just an assumption that concern for other does not completely solve the problem of when to cooperate and when not to. Two of the most studied games in this context is the Prisoner's Dilemma [8] and the Stag Hunt [11] game.

The Prisoner's Dilemma is a game that shows why two individuals might not cooperate, even if it appears that it is in their best interest. Axelrod [8] states that a similar problem occurs in many similar situations where the pursuit of self-interest by each agent leads to a poor outcome for all. The Prisoner's Dilemma game is a general representation of such situation. Axelrod has explored the conditions in which cooperation would emerged by promoting a computer tournament where people could submit their favourite strategy to play the iterative version of the prisoner's dilemma game. The winner for the rounds of the tournament was Anatol Rapoport [12] that submitted the very well know TIT FOR TAT strategy that was based on reciprocity. This very simple strategy that consisted in cooperating in the first move and then doing whatever the other player did in the previous move overcome complex strategies based on Markov processes and Bayesian inference. After analysing the data that resulted from this tournament Axelrod concluded the following. The evolution of cooperation requires that individuals have a sufficiently large chance to meet again so that they have a stake in their future interaction and also that cooperation be based in reciprocity.

The Stag Hunt [11] is a prototype of the social contract [13]. Like in the Prisoner's Dilemma game, each player must choose an action without knowing the choice of the other. If an individual hunts a stag, he must have the cooperation of his partner in order to succeed. An individual can get a hare by himself, but a hare is worth less than a stag.

Skyrms argues that the Stag Hunt does not have the same melodramatic quality as the Prisoner's Dilemma but instead raises its own set of issues. When comparing a two-person Stag Hunt with a two-person Prisoner's Dilemma he noticed the following. If two people cooperate in the Prisoner's Dilemma, each is choosing less rather than more. Specifically, there is a conflict between individual rationality and mutual benefit. In the Stag Hunt, what is rational for one player to choose depends on his beliefs about what the other will choose. The Stag Hunt differs from the Prisoner's Dilemma in that there are two Nash equilibria: when both players cooperate and both players defect. In the Prisoner's Dilemma, in contrast, despite the fact that both players cooperating is Pareto efficient [14], the only Nash equilibrium is when both players choose to defect.

The existence of those two Nash equilibria is just to say that it is best to hunt stag if the other player hunts stag, and it is best to hunt hare if the other player hunts hare. Therefore, it is clear that a pessimist, who always expects the worst, would hunt hare. But it is also true with these pay-offs that a cautions player, who was so uncertain that he though the other player was as likely to do one thing as another, would also hunt hare. Hunting hare is said to be the risk-dominant equilibrium. That is not to say that rational players could not coordinate on the stag hunt equilibrium that gives them both a better pay-off, but it is to say that they need a measure of trust to do so.

A. *Conclusion*

When observing cooperation from a prisoner's dilemma point of view it was concluded that for cooperation to emerge certain conditions have to hold true. Specifically, a player will be more likely to cooperate with another player if there is a high probability of interacting with that player in the future. The same applies to the stag hunt since a repeated prisoner's dilemma is equivalent to a two-person stag hunt. Another important conclusion is that a strategy based on direct reciprocity can overcome even complex strategies. Therefore, if cooperation is established on the basis of direct reciprocity it will endure even if non-cooperative strategies exist. Indirect reciprocity should also be consider and has been identified has an equal important factor that promotes the emergence of cooperation. Indirect reciprocity, also denominated reputation, states that if a player is known as being cooperative than other players more likely will cooperate with him. Basically, what this means is that cooperation can emerge either by inducing a certain behaviour in direct relationships but also through indirect relationships. From the stag hunt game several important conclusion could also be extracted. Skirms argued that the viability of cooperation depends on mutual beliefs, and rest on trust. Therefore, trust is a central concept when studying cooperation and was the property chosen in the case study. We believe that even if mutual beliefs don't exist or if the players are unaware of each other beliefs, cooperation will nevertheless emerge if the level of trust is higher enough.

III. Design and Engineering Methodology for Organizations (DEMO)

DEMO is the approach that supports our proposal for modelling the functioning of an organization. Its roots are in the Ψ-theory, which provides an explanation of the construction and operation of organizations based on four axioms thus contributing to the strong theoretical ground that ensures the formal correctness of its models [2], [3], [4]. DEMO's methodology has already been use successfully in a large number of projects [15], [16], [17].

The operation axiom states that the operation of an organization is constituted by the activities of actor roles, which are elementary chunks of authority and responsibility, fulfilled by subjects. In doing so, these subjects perform two kinds of acts: production acts (P-acts) and coordination acts (C-acts). By performing P-acts, the actors contribute to bringing about the goods or services delivered to the environment of the organization. However, by performing C-acts, actors enter into, and comply with, commitments and agreements towards each other regarding the performance of P-acts.

In this paper, our focus is to provide a systematic way to study both the effects of cooperation in organizational performance and also what are the conditions that foster or promote cooperation. In this manner, we are not so concerned about how a P-act is performed but we put more stress in the C-acts since these are the ones that are focused on the social interactions of the intervening actors.

A coordination act is an act performed by one actor, called the performer, and directed to another actor, called the addressee (Figure 1). It consists of two concurrent acts, the intention act and the proposition act. In the intention act, the performer proclaims its "social attitude" with respect to the proposition. This term was defined by Searle [6] and Dietz [3] used it to distinguish coordination acts from communicative acts in general.

The actors are the active elements of an organization and they are the only ones Dietz considers when modelling the functioning of an organization. Therefore, machines or any other artificial systems

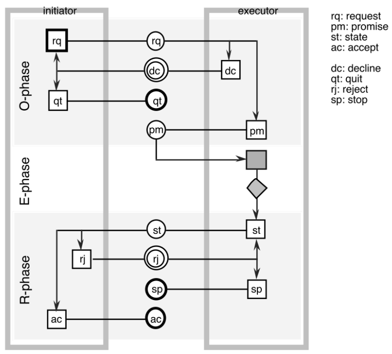

Figure 1. DEMO Transaction Axiom [3]

are consider as supporting actors an never replacing them. Actors are not triggered by events, instead they constantly loop through the actor cycle, in which they deal with their agenda. An *agendum* is a C-fact with a proposed time for dealing with it, to which actor is committed to respond. Action rules guide the actors in dealing with their agenda; there is an action rule for every type of *agendum*. The addressees of these C-acts are other actors, which means that the resulting C-facts are added to the agenda of these other actors. In this way, actors keep supplying each other with work. Dietz described the behaviour of actors as described in common organizational theories where three main factors are taken into account: responsibility, authority and, competence. In this paper we broaden this notion to include other factors borrowed from Game Theory, namely reciprocity, reputation and trust. This is further explained in Section IV-A.

Another important notion we have retrieve from the Ψ-theory is how the C-act are performed and this is explained by the the transaction axiom. This axiom states that C-acts are performed as steps in universal patterns. These patterns, also called transactions, always involve two actor roles (initiator and executor) and are aimed at achieving a particular result. A transaction is developed in three phases: the order phase (O-phase), the execution phase (E-phase), and the result phase (R-phase). In the O-phase the two actors agree on the expected result of the transaction; in the E-phase the executor executes the production act needed to create the anticipated result; and in the R-phase the two actors discuss if the transaction result is equal to the expected one. The general transaction pattern is shown in Figure 1.

In this general pattern, the course that is taken is when the initiator and the executor keep consenting to each other's acts. However, they may also dissent. There are two states where this may happen, namely "requested" and "stated". Instead of promising, one may respond to a request by declining it, and, instead of accepting one may respond to a statement by rejecting it. The reason for declining a request by the executor of a transaction or for rejecting a statement by the initiator is in principle a mixture of the three validity claims. These validity claims where defined by Habermmas [18] and are respectively, claim to truth, claim to justice and claim to sincerity.

This is central to our proposed ABS because since the transaction pattern is fixed, then, we can change how the behaviour of the actors involved is characterized and see the impact of such changes when performing this general transaction pattern.

IV. Agent-Based Simulation (ABS)

Formally, ABS is a computational method that enables a researcher to create, analyse, and experiment with models composed of diverse and heterogeneous agents that interact within an environment [19].

The underlying assumption for using ABS to model reality in organizations is to view organizations as Complex Adaptive Systems that emerge from the interactions among human agents. In this context, to take an agent-based approach means not having to assign an objective to an organization and instead model the agents that comprise it with explicit attention to their individual behaviours and how they interact with each other and the environment.

Agent-based models are characterized by the following [20], [21], [22]:

- A set of agents, their attributes and behaviours. The behaviour can be either according to rational models, behavioural models or rule-based models.
- A set of agent relationships and methods of interaction: An underlying topology of connectedness defines how and with whom agents interact.
- The agents environment: Agents interact with their environment in addition to other agents.
- Model outcomes: simulating a set of agents interacting in an environment provides insights into phenomena related to the part of reality being simulated.

Next section its describe how an ABS can be built using the assumption of DEMO's Ψ-theory and the conclusions drawn from the Prisoner's Dilemma and Stag Hunt game. Also, a simple instantiation of the model was implemented in Netlogo [23].

A. ABM and Cooperation in Business Organizational Settings

The basic units of the model proposed to systematically study the effects of cooperation in organizational performance are a set of agents that can be of two particular types: initiators and executors. These two types correspond to the two actor roles described in DEMO Transaction axiom. These two roles can either represent individual people, groups of people or even different organizations. As described in Section III each of these roles has a particular set of actions that define their behaviour in the context of a transaction as expressed in Figure 1. Combinations of these actions represent different possible paths and results that can happen while the two actor roles interact.

Dietz has a lot more subtleties concerning the Transaction axiom than what is explained here. But, one of our concerns was to keep the model as simple as possible, because the essence of modelling is to simplify things and also, as long as no vital conceptual features are lost, simplicity is the best modelling strategy. Also, the complexity of agent-based modelling should be in the simulated results, not is the assumptions of the model. In this manner when surprising results occur, it will be possible to understand everything that went into the model.

Dietz does not explicitly integrate in DEMO's models how cooperation factors impact the execution of a transaction. Namely, nothing is said about how trust affects or influences what is the actions the initiator or executor chooses while performing a

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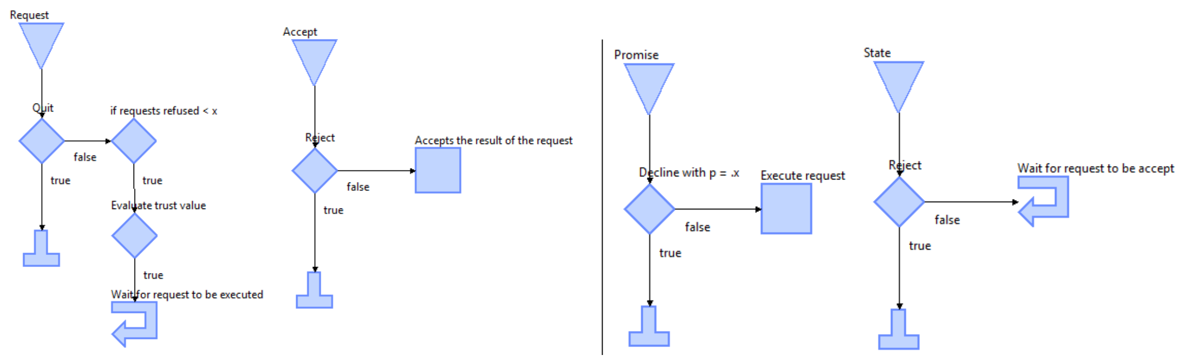

Figure 2. Initiator actions and behaviour (left). Executor actions and behaviour (right)

transaction. Instead, is assumed that the actors involved in an interaction do a "best effort" while performing the transaction. In reality this is not always the case. The individuals that fulfil actor roles in business contexts are self-interest in the sense that they may or might not share the same goals. Also, fostering cooperation among individuals, groups, or even nations is something very much related to culture and context. What could help foster cooperation in some situations might not work across all similar situations. This means that although Axelrod and Skyrms argues that cooperation can emerge when there's reciprocity, attention to reputation and trust, it's not straightforward how this could be integrate in work practices nor what are the underlying conditions to make reciprocity, attention to reputation and trust exist among interacting individuals. Therefore, it would be very interesting and important to understand how we can add this kind of factors to DEMO's transactions and see if this could help shed some light on questions such as: "Does the level of trust between two actors affect the time a transaction takes to be concluded?"; Does the level of trust between two actors affect the probability of futures interactions? If both actors used a reciprocity based strategy will they become more tolerant to faulty situations, like the level of quality of the executor output?

We believe that bringing together DEMO's extensive work in modelling organizations and Axelrod's and Skyrms wonderful work on cooperation could help answer those and other important questions. In order to do an initial test to understand the potential of bringing this body of knowledge together, we have implemented an ABS in NetLogo based on the diagram in Figure 2.

It was assumed that both an initiator and an executor can only have a maximum number of simultaneous transactions. If a initiator has reached this maximum number he will only be able to do a new request after one of the current transactions is finished. Also, we have assumed that if an executor is inactive during a maximum period of time he would be eliminated from the environment. This is a consequence of all the initiators refusing to interact with them due to low level of trust.

In this model, we have used trust to test how this would impact the number of commitments between initiators and executors and also the number of executors that would die out for being inactive too long. We have devised three simple scenarios in order to be able to compare the differences between the results. Among the different scenarios we have change the probability with which an

Scenario	Description	Results
Scenario1	executors never refuse a request $p = 1$	Equilibrium is reach very fast (number of commitments constant $\simeq 490$) and no executors die out for lack of requests ($\simeq 97.9$).
Scenario2	executors refuse a request with a probability $p = .5$	Equilibrium takes longer to be achieve, number of commitments decreases to less than a half ($\simeq 218$) executors die out for refusing requests ($\simeq 82.5$).
Scenario3	executors refuse a request with a probability $p = .2$	Equilibrium takes longer to be achieve, number of commitments is very low ($\simeq 40.7$) and most executors die out($\simeq 33$).

Table I
SCENARIOS AND RESULTS

executor would refuse a request. This probability basically traduces the level of trust between an initiator and an executor. Therefore, the higher the level of trust the higher chances of an executor to fulfil a certain commitment. The details of each scenario and the results after several simulation runs are described in Table I and Figure 3.

Although the assumptions of the presented scenarios are simple, the statements describing the scenarios and the respective conclusions show the potential of using Game Theory, DEMO's Ψ-theory and ABS to study cooperation in organizational settings.

V. CONCLUSIONS AND FUTURE DIRECTIONS

In this paper, we have addressed the problem related to understanding what are the effects of cooperation in business organizational settings. We have started by describing what is cooperation and how it has been studied from a Game Theory point of view. In this context we have described two of the most studied games related to cooperation, namely the Prisoner's Dilemma and the Stag Hunt. These games have been extensively used to understand what are the necessary factors and conditions for cooperation to emerge in a environment populated by self-interested agents. To model the social interactions between two actors we have used DEMO's Ψ-theory. Finally, we have described how a conceptual model based on ABS which included concepts from DEMO and Game Theory could be use to study the effects of cooperation in business organizational settings. A very simple instantiation of this

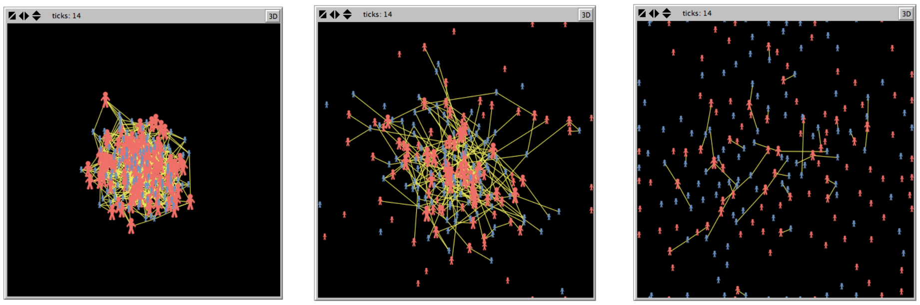

Figure 3. Scenario 1 (left). Scenario 2 (center) Scenario 3 (right)

model was used to simulate three different scenarios from which some conclusions were drawn. These conclusion were merely representative of the potential of bringing these concepts together. To be able to reach conclusive or even breakthrough insights it would be necessary to include more details and more though-out assumptions. Namely, extend the interaction to n-person instead of just 2-person transactions.

Axelrod, a part from studying the two-person Prisoner's Dilemma, he was also concerned in understanding how cooperation could emerge when many people interact with each other in groups rather that in pairs. In a n-person Prisoner's Dilemma, the dynamics that evolve to sustain cooperation are different from the two-person version. This is due to the fact that in a n-person Prisoner's Dilemma the players have no way of focusing their punishment on someone in the group who has failed to cooperate. From this realization, Axelrod developed a new game, the "norms game", that allowed players to punish individuals who do not cooperate. Another interesting experiment would be to add to the simulation the ability for executors to create groups among them to compete with other groups of executors. Finally, failing to cooperate sometimes is not intentional but instead the result of a misunderstanding, for example, the previous action was not understood or the current action failed to be correctly implemented. In order to also incorporate this possibility, it would be necessary to add some kind of "noise" to the model and the ability for executors to show contrition and generosity.

Extending the interaction to n-person transactions involves considering a lot more factors that is no doubt a challenge but it could potentially provide very valuable insights to the questions raised in this paper. Also, in the possibility of these experiments reach conclusive statements about how cooperation could be promoted in such settings it could help to enhance DEMO's Ψ-theory models in order to better accommodate the social side of business and therefore bridge the gap that still exists in many of the approaches of Enterprise Engineering.

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References

[1] R. Magalhães, *Organizational Knowledge and Technology*. Edward Elgar Publishing, 2004.

[2] J. L. G. Dietz, "The atoms, molecules and fibers of organizations," *Data Knowl. Eng.*, vol. 47, no. 3, pp. 301–325, 2003.

[3] J. Dietz, *Enterprise Ontology: Theory and Methodology*. Springer, 2006.

[4] J. Barjis, "A business process modeling and simulation method using demo," in *Enterprise Information Systems*, vol. 12 of *Lecture Notes in Business Information Processing*, pp. 254–265, Springer Berlin Heidelberg, 2009.

[5] F. Dignum and J. Dietz, "Communication modelling: The language/action perspective," in *Second International Workshop on Communication Modeling (LAP 97)*, 1997.

[6] J. Searle, *Speech Acts: An Essay in the Philosophy of Language*. Cambridge University Press, 1969.

[7] A. Caetano, A. Assis, and J. Tribolet, "Using business transactions to analyse the consistency of business process models," *Hawaii International Conference on System Sciences*, vol. 0, pp. 4277–4285, 2012.

[8] R. Axelrod, *The Evolution of Cooperation*. Basic Books, 1985.

[9] R. Axelrod, *The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration*. Princeton University Press, 1997.

[10] K. Leyton-Brown, *Essentials of Game Theory: A Concise, Multidisciplinary Introduction*. Morgan and Claypool Publishers, 2008.

[11] B. Skyrms, *The Stag Hunt and the Evolution of Social Structure*. Cambridge University Press, 2003.

[12] A. Rapoport and A. Chammah, *Prisoner's Dilemma*. Ann Arbor, Mich.: University of Michigan Press, 1965.

[13] T. Hobbes, *Leviathan*. London: Penguin Books, 1985.

[14] M. J. Osborne, *An Introduction to Game Theory*. Oxford University Press, 2009.

 ISBN: 978-1-61208-234-9

[15] A. Caetano and J. Tribolet, “On the use of a role ontology to consistently design business processes,” *Building the e-World Ecosystem*, pp. 163–176, 2011.

[16] D. Aveiro, A. Silva, and J. Tribolet, “Control organization: A demo based specification and extension,” *Advances in Enterprise Engineering V*, pp. 16–30, 2011.

[17] M. Zacarias, H. Pinto, R. Magalhães, and J. Tribolet, “A context-aware and agent-centric perspective for the alignment between individuals and organizations,” *Information Systems*, vol. 35, no. 4, pp. 441–466, 2010.

[18] J. Habermas, *The Theory of Communicative Action, Volume 1: Reason and the Rationalization of Society*. Beacon Press, 1985.

[19] N. Gilbert, *Agent-Based Models (Quantitative Applications in the Social Sciences)*. Sage Publications, Inc, 1998.

[20] M.-H. Chang and J. J. Harrington, “Agent-based models of organizations,” in *Handbook of Computational Economics* (L. Tesfatsion and K. L. Judd, eds.), vol. 2 of *Handbook of Computational Economics*, ch. 26, pp. 1273–1337, Elsevier, 00 2006.

[21] J. Miller and S. Page, *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*. Princeton University Press, 2007.

[22] C. Macal and M. North, “Tutorial on agent-based modelling and simulation,” *Journal of Simulation*, vol. 4, no. 4, pp. 151–162, 2010.

[23] U. Wilensky, “NetLogo.” http://ccl.northwestern.edu/netlogo/, 1999. [Online; accessed 05-November-2012].