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The Development of Social Simulation as Reflected in the First Ten Years of *JASSS*: a Citation and Co-Citation Analysis

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Abstract

Social simulation is often described as a multidisciplinary and fast-moving field. This can make it difficult to obtain an overview of the field both for contributing researchers and for outsiders who are interested in social simulation. The Journal for Artificial Societies and Social Simulation (*JASSS*) completing its tenth year provides a good opportunity to take stock of what happened over this time period. First, we use citation analysis to identify the most influential publications and to verify characteristics of social simulation such as its multidisciplinary nature. Then, we perform a co-citation analysis to visualize the intellectual structure of social simulation and its development. Overall, the analysis shows social simulation both in its early stage and during its first steps towards becoming a more differentiated discipline.

Keywords:Citation Analysis, Co-Citation Analysis, Lines of Research, Multidisciplinary, Science Studies, Social Simulation

Introduction

1.1 Social simulation can be considered a young and fast-developing field. While it started with only a small number of scientists who met at workshops and exchanged ideas (Gilbert 1998), the discipline has grown quickly and become more and more institutionalized over time. Significant milestones for connecting the groups of scientists to each other are the foundation of regional associations, such as the North American Association for Computational Social and Organizational Science (NAACSOS), the European Social Simulation Association (ESSA) and the Pacific Asian Association for Agent-based Approach in Social Systems Sciences (PAAA) (Moss 2002), and of now global conferences, such as the World Congress in Social Simulation (WCSS). Social simulation's rapid development is also reflected in its publication outlets. In addition to workshops and conferences being documented in edited volumes, scientific journals such as the *Journal for Artificial Societies and Social Simulation* (JASSS), the *Journal of Economic Interaction and Coordination* (JEIC) and *Computational and Mathematical Organization Theory* (CMOT) (Gilbert 1998; Namatame et al. 2006; Carley 1995) now specialize in social simulation. Particularly the latter, the establishment of specialized journals is usually considered an important milestone in the institutionalization of scientific disciplines (Thackray and Merton 1972).

1.2 However, given the field's increasing size and dynamic character, it becomes more and more difficult to obtain an overview of social simulation and its development over time. This is potentially detrimental to the field for three reasons. First, researchers active in a specific area of social simulation may tend to adopt a particular perspective which can not only introduce a certain bias, but even more importantly also poses the danger of missing key developments in the field. Second, the difficulty of gaining an overview can increase the costs of entry into the field as it may appear too complex for newcomers. Third, a lack of reliable information on the current state of the field might also be an impediment for addressing policy related issues like discussing the discipline's current state and its future direction.

1.3 In order to overcome the potential weaknesses, this paper aims at mapping the intellectual structure of social simulation and its development. This is to be achieved by a bibliometric analysis of the first ten years of *JASSS*.[1] As the journal has completed its tenth year, it seems an appropriate time for taking stock of what has happened since its launch. In particular, we address the following questions by means of citation and co-citation analysis: (1) What are the most influential publications in the field? What are their characteristics? (2) What lines of research exist in the field of social simulation? How are these lines of research grouped? (3) What developments have occurred over time? Can any important changes be identified?

1.4 The remainder of this paper is organized as follows. In the next section we describe our method and data set. Then, we present the most influential publications of social simulation based on citation analysis and discuss further characteristics of the discipline, such as its

multidisciplinary nature. Subsequently, co-citation analysis is used to identify different lines of research and to map their development over time. The discussion of our results and suggestions for future research conclude the paper.

Method and Data Set

2.1 One possible way of looking at science and its development is to view it as a complex and adaptive system. In line with this perspective, first simulation studies already exist that reproduce some of the typical relationships found in quantitative studies on science such as Lotka's law (Gilbert 1997). The approach adopted for this paper complements those endeavors by providing empirical data. Contrary to older approaches to quantitative studies on science, we also draw on social network analysis as a main element for our analysis. This allows for visualizing the intellectual structure of a field.

2.2 More specifically, the two methods we use are citation and co-citation analysis. Both are well established bibliometric methods for analyzing the structure of scientific disciplines (Osareh 1996a; Osareh 1996b). Our study focuses on scientific publications rather than scientific authors as the main unit of analysis (similarly Gilbert 1997). Citation analyses investigate the relationships between citing and cited publications. A citation is interpreted as a measure of the importance assigned to the source or its author. This method is well suited for identifying influential publications and, thus, for addressing our first research question.

2.3 Co-citation analyses examine the relationships between several cited publications. They allow us to draw conclusions about the internal structure of research and about the existing lines of research (our second research question). A co-citation exists between two publications or researchers when they are cited in the same source document, i.e. when the authors are listed in the same bibliography. The number of co-citations is interpreted as a proximity measure of the sources or their authors. A certain number of co-citations must exist in order for the results to be interpreted.[2] One of the main advantages of co-citation analysis is its ability to capture the perspectives of a large number of researchers in the same field. Moreover, this kind of analysis does not affect the results and can unearth relationships that the people providing the information are not aware of and/or that are not transparent due to the topic's complexity. It is important to note that the networks derived from co-citation analysis do not necessarily depict groups of individuals that are actually linked, for example through being associated with the same institution. The individuals are just perceived as being related.

2.4 Co-citation research embraces a large number of different methods to determine co-citation clusters. For the purposes of the present study, we choose a method that is used successfully before in comparable studies to identify distinctive lines of research (Ahlgren et al. 2003; Gmür 2003; Meyer et al. 2008). In order to track the development of social simulation and to answer our third research question, we cut the whole time period of 10 years in half and define two time periods that are analyzed separately (Period 1: 1998-2002, Period 2: 2003-2007).

2.5 The analysis focuses on the most cited publications in an attempt to reduce the complexity of the analysis. Therefore, publications had to yield a minimum absolute citation value of three to be included in the co-citation analysis, i.e. all sources are cited in at least three *JASSS* articles within one of the two periods. This resulted in a remaining sample of 91 (1998-2002) and 202 (2003-2007) sources respectively.

2.6 However, absolute citation values are not suitable for generating clearly defined clusters. Due to their wide dissemination, the most cited sources tend to be co-cited in clusters more frequently, even though less cited sources might be more closely related to each other in terms of content. To account for this, the absolute co-citation value between two sources needs to be put in relation to the frequency of citation. The so-called CoCit score is well suited for this purpose (Gmür 2003) and represents a relative co-citation value for two sources A and B. It is scaled to a range between 0 and 1 and can be calculated using the following formula:

$$\mathrm{CoCit}_{AB} = \frac{(\text{co-citation}_{AB})^2}{\min(\text{co-citation}_A; \text{co-citation}_B) \cdot \text{mean}(\text{co-citation}_A; \text{co-citation}_B)}$$

2.7 Co-citation relationships are selected for analysis if their CoCit scores are high.[3] The resulting co-citation networks comprise several clusters. Various types of clusters exist such as isolated pairs, co-citation chains, co-citation stars, or a number of differently sized interlinked groups. In this paper, we refer to a group as a cluster when it contains at least three sources that are in turn linked by at least three strong co-citation relationships.

2.8 In retrieving and preparing our data set, we benefited from the open online access to all *JASSS* articles.[4] As the articles and their respective references are available in HTML format, we implemented a Java-based HTML Parser which automatically extracted the references from the *JASSS* articles. In addition, some *JASSS* articles had to be added manually to the data set as they were only available in PDF format.

2.9 An essential step for preparing the data set is to identify and mark citations which refer to the same publication source. That is why we assigned the same source ID to all such references in a two-tiered process. In a first step, we had this task carried out automatically using the HTML Parser. This initial allocation was based on an automated assessment of the citation's content and assigned equal source IDs to similar references.[5] In a second step, we manually refined the raw data generated by the parser. We checked the data set for its completeness ensuring that all references were extracted by the HTML Parser. Then, we verified the references' source ID that the HTML Parser had assigned to them. We sorted the data set by source ID and author in order to ensure that both citations with the same source ID indeed refer to the same publication source and that citations referring to different publications have different source IDs. Since not all references had been entered homogenously by the authors of the *JASSS* publications, this represented an important precondition to provide reliable answers to the questions posed in the citation and co-citation analyses. Table 1 gives an overview of the resulting data set.

Table 1: Data Set

	1998-2002			**2003-2007**			**SUM**
Number of citations	2873			5375			8248
Number of *JASSS* articles	110			184			294
Avg. citations per article	26.12			29.21			-
Frequency of occurrence of citations in *JASSS* (x_k)	f_k[6]	p_k	cp_k	f_k	p_k	cp_k	
1	2078	87.94%	87.94%	3765	87.33%	87.33%	
2	190	8.04%	95.98%	336	7.79%	95.13%	
3	55	2.33%	98.31%	104	2.41%	97.54%	
4	15	0.63%	98.94%	47	1.09%	98.63%	
5	8	0.34%	99.28%	26	0.60%	99.23%	
> 5	17	0.72%	100.00%	33	0.77%	100.00%	
Number of different citation sources	2363			4311			
Avg. source age	10.85			10.91			

2.10 Before we present the results of the citation and co-citation analysis, we would like to comment on the data set. First of all, the increased number of articles published in *JASSS* over the two time periods is noteworthy. Although this leads to a rise in the total number of citations, the number of citations per article increases only slightly over the two time periods. The latter observation is important for our co-citation analysis as the probability of a co-citation in an article remains quite stable over time. Second, examining the frequency of occurrence reveals that most citations in *JASSS* occur once or twice with only a minority being cited regularly. This is a typical pattern found in many bibliometric studies (Lotka's law) and allows for focusing on the most cited publications for the co-citation analysis.[7] Finally, the average source age of about eleven years is very similar for the two time periods. While this value seems rather high compared to the average source age of four years in natural science, it really represents a typical value which comparable studies have found for a variety of social science disciplines (see Bricker 1988).

Citation Analysis Results

3.1 The citation analysis explores three main aspects for both time periods: influence of an individual publication, types of publication outlets and their respective significance, and distribution of academic disciplines associated with the publication outlets. Each area is interpreted with regard to the development of social simulation as a new academic field. Some facets were then analyzed in more detail to allow for more in-depth results.

3.2 As stated, we started by using citation analysis to identify the most influential publications in the field. Table 2 lists the most-cited sources and where they have been published for both time periods. To provide a measure for the importance of an individual publication we provide its relative citation value which is the total number of citations divided by the total number of analyzed articles for the respective time period. The fields marked in gray in Table 2 indicate that the source was published in a journal.

3.3 Examining the first time period reveals that the so-called "classics" of social simulation dealing with fundamental, often methodological issues rank among the six most-cited sources. The high citation value of the most cited source, Epstein/Axtell (1996), is remarkable showing that it is found in every fifth publication. Another notable fact is that Axelrod is the

author of three out of the six most influential publications. In general, the list of the most cited sources in the first period tends to be comprised of publications that deal with general aspects of the simulation method. Books represent the dominant publication outlet in this period. Even at the early stage, social simulation appears to emerge as a multidisciplinary field drawing upon publications from a wide range of disciplines such as economics and evolutionary biology.

3.4 The picture changes for the second period. Only six publications from the previous period are found again among the most-cited sources. In light of this observation, it is even more striking that five of those six publications lead the list in the second period. Axelrod (1984) is now the most cited source. It is closely followed by Epstein/Axtell (1996) that used to be at the top, but has lost half of its citation value in the second period. Contrary to the continuity at the top of the list, the remainder of the most cited sources fluctuates greatly over time. A shift in priorities can also occur in other areas. Many of the new publications now deal with concrete topics of social simulation, such as "opinion dynamics" or "networks", rather than addressing fundamental or methodological issues. This is accompanied by a clear shift away from books and towards journals as the dominant publication outlet. Finally, examining contributions from other disciplines reveals that publications from other disciplines such as economics and sociology are still cited - albeit less often than in the previous period.

	1998-2002			2003-2007		
1.	Epstein / Axtell (1996): Growing Artificial Societies: Social Science from the Bottom Up	Book	21.0%	Axelrod (1984): The Evolution of Cooperation	Book	13.3%
2.	Gilbert / Troitzsch (1999): Simulation for the Social Scientist	Book	12.4%	Epstein / Axtell (1996): Growing Artificial Societies: Social Science from the Bottom Up	Book	11.6%
3.	Axelrod (1984): The Evolution of Cooperation	Book	11.4%	Gilbert / Troitzsch (1999): Simulation for the Social Scientist	Book	11.0%
4.	Axelrod (1997): The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration	Book	10.5%	Axelrod (1997): The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration	Book	9.9%
5.	Dawkins (1976): The Selfish Gene	Book	8.6%	Axelrod (1997): Advancing the Art of Simulation in the Social Sciences	Book-Chapter	6.6%
6.	Axelrod (1997): Advancing the Art of Simulation in the Social Sciences	Book-Chapter	7.6%	Watts / Strogatz (1998): Collective Dynamics of Small-World Networks	Nature	6.1%
7.	Hegselmann / Flache (1998): Understanding Complex Social Dynamics: A Plea for Cellular Automata Based Modelling	JASSS	7.6%	Barreteau et al. (2001): Role-playing Games for Opening the Black Box of Multi-Agent Systems: Method and Lessons of its Application to Senegal River Valley Irrigated Systems	JASSS	6.1%
8.	Doran / Gilbert (1994): Simulating Societies: An Introduction	Book-Chapter	6.7%	Axtell et al. (1996): Aligning Simulation Models: A Case Study and Results	CMOT	5.5%
9.	Conte / Castelfranchi (1995): Cognitive and Social Action	Book	6.7%	Hegselmann / Krause (2002): Opinion Dynamics and Bounded Confidence: Models, Analysis, and Simulations	JASSS	5.5%
10.	Gilbert / Conte (1995): Artificial Societies: The Computer Simulation of Social Life	Edited Book	6.7%	Deffuant et al. (2002): How can extremism prevail? A study based on the relative agreement interaction model	JASSS	5.5%
11.	Nelson / Winter (1982): An Evolutionary Theory of Economic Change	Book	6.7%	Edmonds / Hales (2003): Replication, Replication and Replication: Some Hard Lessons from Model Alignment	JASSS	5.0%
12.	Arthur et al. (1997): The Economy as an Evolving Complex System II	Edited Book	5.7%	Deffuant et al. (2000): Mixing Beliefs among Interacting Agents	ACS	4.4%
13.	Arthur (1989): Competing Technologies, Increasing Returns, and Lock-In by Historical Events	Eco J	5.7%	Luhmann (1984): Soziale Systeme	Book	4.4%
14.	Troitzsch (1997): Social Science Simulation: Origins, Prospects, Purposes	Book-Chapter	5.7%	Nelson / Winter (1982): An Evolutionary Theory of Economic Change	Book	4.4%
15.	Conte et al. (1997): Social Simulation: A New Disciplinary Synthesis	Book-Chapter	5.7%	Macy / Willer (2002): From Factors to Actors: Computational Sociology and Agent-Based Modeling	ARS	4.4%
16.	Conte / Castelfranchi (1995): Understanding the Functioning of Norms in Social Groups through Simulation	Book-Chapter	5.7%	Polhill et al. (2005): The Ghost in the Model	JASSS	4.4%
17.	Kauffman (1993): The Origins of Order	Book	5.7%	Axelrod (1997): The Dissemination of Culture: A Model with Local Convergence and Global Polarization	JCR	4.4%

Table 2. Citation Values of the Most Cited Sources for the Two Time Periods

3.5 The development of the results over time points towards an interesting process that becomes particularly evident in the lower ranks of the list. One can argue that the results from the first period show the field at an early stage, wherein researchers often refer to fundamental issues concerning simulation as a method (besides the constant publications at the top of the list, see also e.g. Doran/Gilbert (1994), Troitzsch (1997) or Conte et al. (1997)). As the main publication outlets for this kind of work available at that time were books and edited volumes, these publication outlets naturally dominate the list of the most-cited sources during this period as well. In the second period, a differentiation can be observed. The sources' content is now more specific for the respective topics. To a certain extent, publications already appear in journals that specialize in social simulation, such as *JASSS* or *CMOT*.

3.6 The shift in publication outlets represents a typical pattern found in the maturation of some other young disciplines (Nerur et al. 2008).[8] That is why we re-tested this aspect for the entire data set after having elicited it for the most cited sources. We classified the sources according to the type of publication, i.e. journal publications, books, book chapter, etc., and calculated the share of the different categories. To visualize the change over time in more detail, we performed this analysis in a first step for each year individually instead of collapsing them again into two major time periods (see Figure 1).

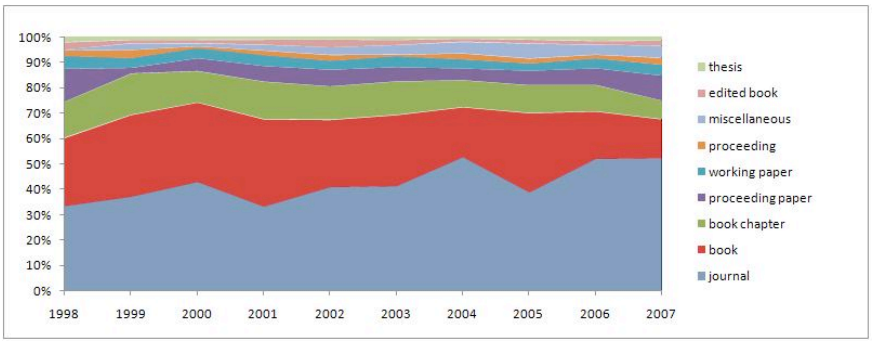

Figure 1. Publication Sources over 10 Years of *JASSS*

3.7 The results of this analysis support the hypothesis concerning an increasing relevance of journals for the field of social simulation. Figure 1 illustrates the share of journal publications rising over time, in particular at the cost of books and book-chapters. In a second step, we wanted to test whether this trend can be substantiated irrespective of minor fluctuations. To accomplish this, we compared the change of the respective shares for the two time periods (see Figure 2) and tested whether the observed differences are also statistically significant.

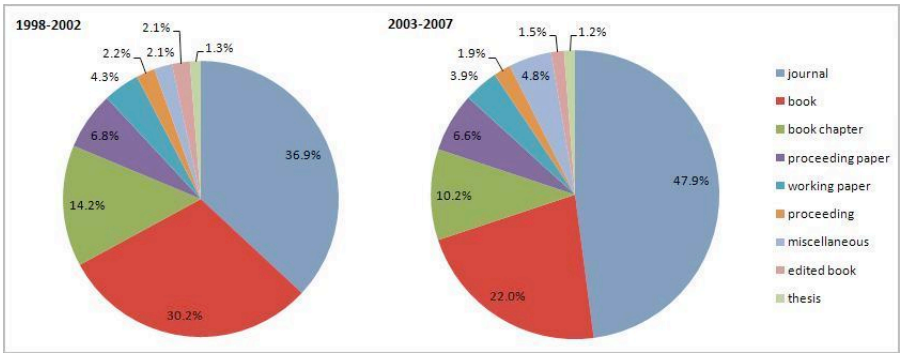

Figure 2. Publication Sources over the Two Time Periods

3.8 The more condensed analysis shows an increase in the share of cited journal publications from 36.9% in period 1 up to 47.9% journal publications in period 2. At the same time, the percentage of cited books and book-chapters decreases from 44.4% to 32.2%. The relevance of proceedings and papers in proceedings, which are especially found in disciplines related to computer science, remains stable at a level of about 9%. The relevance of other publications outlets essentially remained at the same (low) level. Both differences and the corresponding changes were tested for statistical significance and were clearly supported by the results of the χ^2-test (increase of journal publications: $\chi^2 = 90.35$; $p < 0.001$; reduction of books and book-chapters: $\chi^2 = 122.58$; $p < 0.001$).

3.9 Finally, we were interested in finding out to what extent claims concerning the multidisciplinary nature of social simulation were justified based on our citation data. For this purpose, we identified the journals that had been cited by authors in *JASSS* and ranked them according to their importance. The resulting list offers a first glance on the multidisciplinary nature of social simulation. This conclusion clearly implies that the range of disciplines associated with specific journals also reflects the range of academic disciplines relevant for social simulation. Figure 3 displays the shares of different journals and lists the 15 most frequently cited journals in *JASSS*.

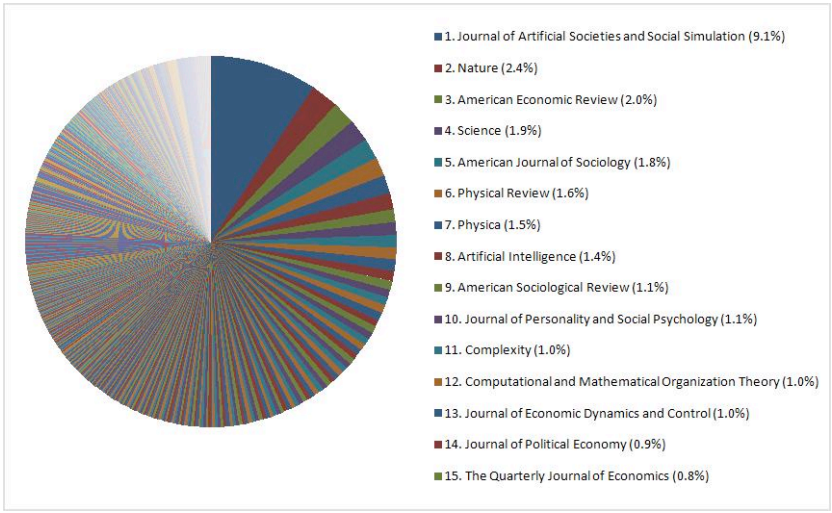

Figure 3. Most Frequently Cited Journals in *JASSS* between 1997 and 2008

3.10 It can be immediately determined from the pie chart in Figure 3 that the journal sources for social simulation are very diverse. Furthermore, examining the most frequently cited journals list in the same figure establishes that the journals stem from a variety of disciplines and, thus, supports the idea of social simulation being strongly multidisciplinary in nature. This diversity is remarkable as many other research fields are dominated by only a few journals.[9] The most cited journal in *JASSS* is *JASSS* itself with a share 9.1%. The next most cited journals are *Nature*, *American Economic Review*, *Science*, *American Journal of Sociology*, *Physical Review*, *Physica*, *Artificial Intelligence*, *American Sociological Review*, *Journal of Personality and Social Psychology*, *Complexity*, *Computational and Mathematical Organization Theory*, and *Journal of Economic Dynamics and Control*—all of them holding a share of at least 1%. These journals originate from very different disciplines such as economics, computer science or psychology. The results from Figure 3 indicate that *JASSS* has emerged as the central location for academic exchange on social simulation without compromising on the field's multidisciplinary nature. Insights from many different research fields continue to be integrated into and contribute to the field's development. The high level of multidisciplinarity is particularly remarkable in comparison to other disciplines.[10]

3.11 To explore the multidisciplinary nature of social simulation even further, we conducted a subsequent analysis concerning the disciplinary origins of the journal citations. To ensure an appropriate categorization of academic disciplines, we adopted the subject classification of the Institute of Scientific Information (ISI; now Thomson ISI, Philadelphia, PA). According to this subject classification, each journal included in the SCII/ISI is assigned to one or several subject categories. We were able to allocate 70.1% of the references to journals to one or more subject categories following the SCII/ISI classification. If a journal was assigned to more than one category, we distributed its share evenly across all respective categories.[11] Figure 4 summarizes the results of this analysis and presents the shares of the ISI subject categories.[12]

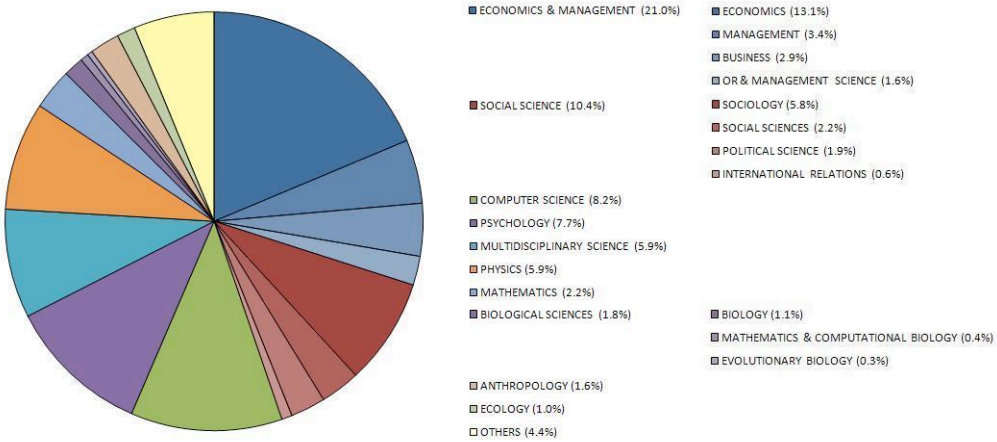

Figure 4. Disciplines of Journal Citations between 1997 and 2008

3.12 The results of our analysis enable us to strengthen our understanding of the multidisciplinary nature of social simulation in two ways. First, they confirm an assumption derived from Figure 3. The works published in *JASSS* refer indeed to journals from very different disciplines such as economics, computer science and psychology. The multidisciplinary nature of social simulation is also reflected in the large share of cited journal references (5.9%) that ISI explicitly classified as multidisciplinary. Second, no single discipline clearly contributes a clear majority of the journal citations. While some research streams like economics & management may be more influential than others at points, the overall claim that social simulation is a multidisciplinary field is clearly supported. The analysis even allowed for a more detailed specification with respect to individual disciplines.

3.13 Overall, the results of the citation analysis empirically support the dynamic and interdisciplinary character of social simulation. Moreover, the shift in publication outlets is remarkable, as it gives an indication for the maturation of the field.

Results Co-Citation Analysis

4.1 While the citation analysis gave us a good first impression of social simulation's development and character, co-citation analysis allows for a further evaluation of the discipline's structure and structural development. In order to maintain cohesion between the two forms of analysis, the co-citation analysis refers to the same two time periods (1997-2002 and 2003-2007). We employed the social network analysis tool Organizational Risk Analyzer (ORA) to visualize the resulting co-citation network.[13] When strong enough Co-Cit scores exist between publications (i.e. a CoCit score above 0.25), they are represented as nodes in the network with their size designating the number of links leading to a node. The more links lead to certain publication, the larger is the node and the more central is the publication's position in a certain part of the network.

4.2 The resulting clusters are numbered according to their size in Figures 5 and 6. While a cluster's size denotes its significance, its density shows how many of the possible relationships between sources actually exist.[14] The later indicates the cohesiveness between the sources in a cluster (Iacobucci 1994:103). Moreover, the existence of many dense clusters points towards a focused discussion in a field (Nerur et al. 2008). A large number of compact clusters is to be interpreted as a differentiated discussion with various areas of focus. In contrast to such a distinct pattern, a field in its very early development stage has been described as "being a diffuse, unfocused area of inquiry" (Thackray and Merton 1972).

4.3 Therefore, a look at both the number of clusters and their density already provides a first insight into the structure of the discussion. A subsequent examination of the clusters can further reveal the extent to which clearly defined lines of research can be identified. For this more in-depth investigation, we initially look for possible thematic focal points. Starting with the sources at the center of a cluster is the most obvious approach as they feature the highest number of links to the other sources in a cluster. The suggested cluster designations follow the respective cluster numbers in the network representations.[15]

4.4 The first co-citation network covers the period from 1998 to 2002. It comprises 48 of the 91 most-cited sources, or 52.7%,[16] which includes a total of only two clusters as shown in Figure 5.[17]

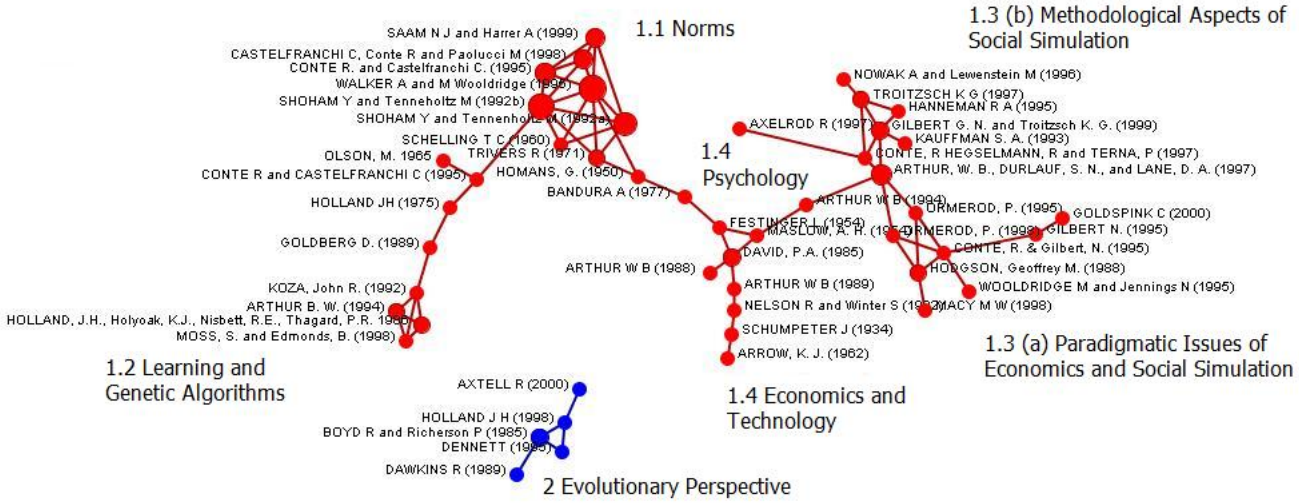

Figure 5. Co-Citation Network 1998-2002

4.5 Cluster 1 has a total of 43 sources making it very large. As it is also widely ramified, we break it down into sub-groups which can be characterized more easily according to their primary focus.

- Group 1.1 represents the strongest thematic focal point within cluster 1. It consists of nine well-linked sources indicating a focused area of inquiry. Similar to its central articles by Walker/Wooldridge (1995) and Shoham/Tennenholtz (1992), most contributions deal with the study of norms and conventions via simulation.
- Group 1.2 contains eight sources with a small, dense center of four publications. In line with the core articles by Koza (1992), Moss (1998), Holland (1986) and Arthur (1994), most contributions to this group focus on learning and genetic algorithms.
- Group 1.3 encompasses 17 loosely connected sources and can be divided into two sub-areas. The ten contributions of Subgroup 1.3a center on the publications by Gilbert/Conte (1995), Hodgson (1988), Ormerod (1995) and Ormerod (1998). They deal with paradigmatic issues of economics and social simulation. The other seven publications belong to Subgroup 1.3b that predominantly addresses methodological aspects of social simulation. Key publications for this subgroup are Gilbert/Troitzsch (1999), Troitzsch (1997) and Conte/Hegselmann/Terna (1997).
- Group 1.4 consists of nine sources. David (1985) and two classics from psychology - Maslow (1954) and Festinger (1954) - form the group's small core. With David (1985) as the starting point, a citation chain can also be identified within the group. This chain focuses on economics and technology as exemplified by Arthur (1989).
- Finally, the much smaller Cluster 2 comprises five contributions. The central articles are those of Boyd/Richerson (1985), Holland (1998) and Dennett (1995). The group captures an evolutionary perspective.

4.6 An evaluation of the origin of the sources in the clusters lends further support to the proposition of social simulation being multidisciplinary in nature. Publications from a variety

of disciplines are part of the network: psychology (e.g. Maslow (1954) or Festinger (1954)), economics (Schumpeter (1934) or David (1985)), sociology (Homans (1950)), or biology (Dawkins (1989)). Many of those sources are considered classics in their respective field. The integration of these sources in the intellectual structure underscores once more the importance of basic ideas from other fields for the discourse in social simulation.

4.7 In comparison to the first time period, the co-citation network covering the period from 2003 to 2007 features a much more differentiated structure (see Figure 6). It includes 123 of the 202 most-cited sources (60.8%) and spreads over 7 clusters.

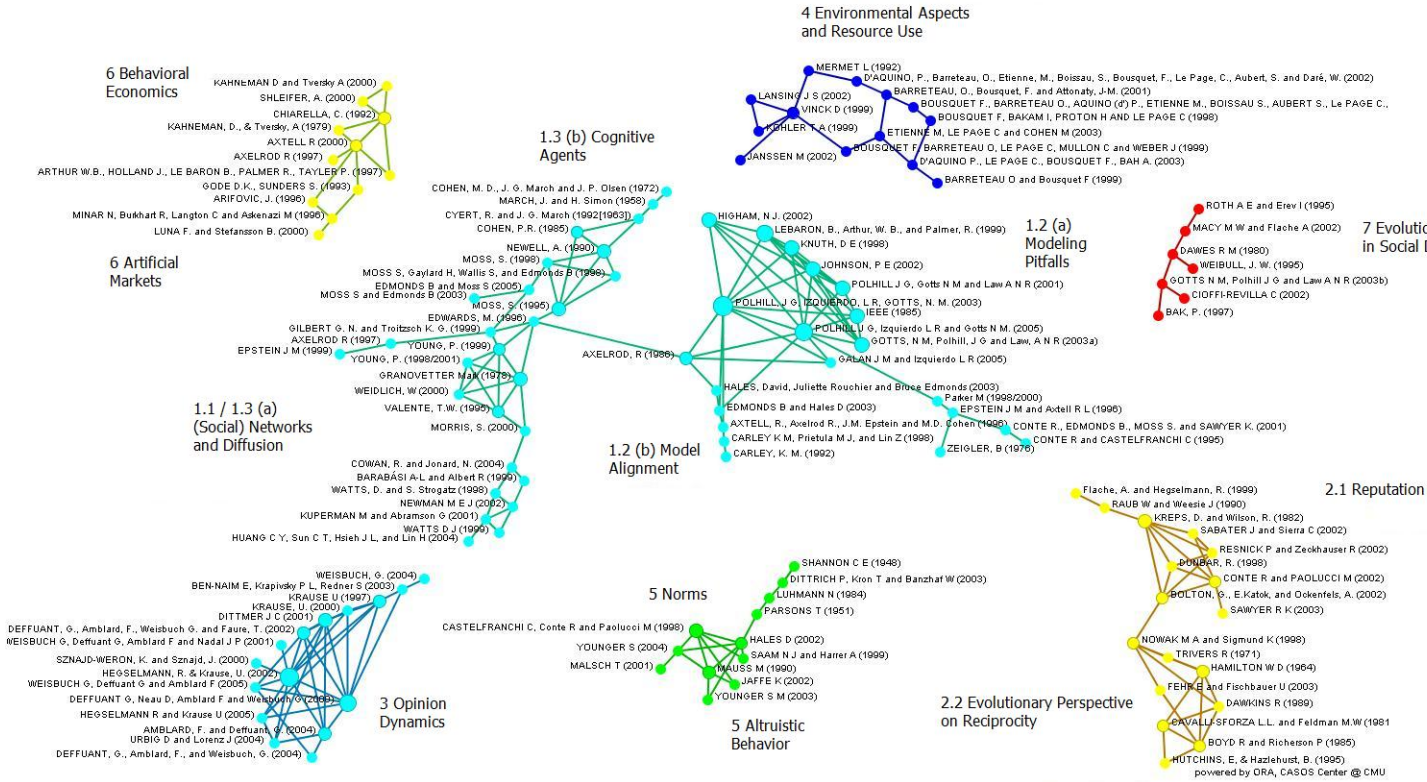

Figure 6. Co-Citation Network 2003-2007

4.8 Exploring the density of the network in the second time period reveals more compact clusters. However, there are still some larger clusters that exhibit a looser structure. We refrain from defining larger clusters in their entirety once more and highlight the different groups within large clusters instead. This approach yields 12 groups.

- Group 1.1 encompasses seven publications. The sources around the central publications include Kuperman/Abramson (2001) as well as Newman (2002) and deal with networks and diffusion.
- Group 1.2 has a total of 21 interlinked sources covering several topics. It can be divided into two subgroups. Subgroup 1.2a is relatively dense and comprises eleven contributions grouped around the works of Polhill/Izquierdo/Gotts (2005), Polhill/Izquierdo/Gotts (2003) and LeBaron/Arthur/Palmer (1999). Its thematic focus is on simulation modeling pitfalls. The central publications of Subgroup 1.2b, which consists of five sources, address simulation model alignment issues such as Edmonds/Hales (2003) and Axtell/Axelrod/Epstein/Cohen (1996).
- Group 1.3 includes 20 sources. However, not all of them are closely linked. Two thematic groups can be identified within it. Seven densely grouped sources form Subgroup 1.3a around the publications by Young (1999) and Granovetter (1978). The contributions in this group focus on diffusion and social networks. Subgroup 1.3b encompasses ten publications. The articles by Newell (1990) and Moss (1995) take a central position. This group focuses on cognitive agents within organizational structures.
- Group 2.1 has nine interlinked contributions; it revolves around the issue of reputation and is centered on Kreps/Wilson (1982), Conte/Paolucci (2002) and Bolton/Katok/Ockenfels (2002). The group's thematic focus corresponds to a ESSA special interest group which is also named Reputation.
- Group 2.2 is constituted by eight publications united through their evolutionary perspective on culture and reciprocity. Central sources are Boyd/Richerson (1985) and Nowak/Sigmund (1998).
- Group 3 is large and compact. The focal articles are those by Hegselmann/Krause (2002) and Deffuant/Neau/Amblard/Weisbuch (2000). All 15 articles in the group deal with opinion dynamics.
- Group 4 is a less dense group and comprises 13 publications. Environmental aspects

and resource use compose its main focus and many sources follow a participative modeling approach. This is supported by the fact that the book by Vinck (1999) emerges as the source with the highest centrality. Participative modelers often refer to that particular publication when they describe modeling as an intermediary object (e.g. Barreteau and others 2003).

- Group 5 comprises 12 sources. It features a densely linked core of seven sources. The contributions around Castelfranchi/Conte/Paolucci (1998) and Hales (2002) deal with the study of norms, while publications around Jaffe (2002) focus on altruistic behavior. It should be noted that this cluster contains two sources from the norms cluster described for the first time period, i.e. Castelfranchi/Conte/Paolucci (1998) and Saam/Harrer (1999).
- Group 6 encompasses eleven publications with Axtell (2000) and Chiarella (1992) as two central publications. Its contributions focus on behavioral economics and also include classic publications in this respect such as Kahneman/Tversky (1979). They are complemented by the publications of Gode/Sunder (1993) and Arifovic (1996) on artificial markets which represent a topic related to behavioral economics.
- Finally, the small and less interlinked Group 7 comprises seven sources covering evolution and learning in social dilemmas such as Dawes (1980) and Gotts/Polhill/Law (2003).

4.9 An evaluation of the origin of the sources in the clusters lends further support to the proposition of social simulation being multidisciplinary in nature once again. There are sources from economics (Kreps/Wilson (1982)), organization theory (Cyert/March (1963) and March/Simon (1968)) or sociology (Parsons (1951) and Luhmann (1984)). Again, many of them are considered to be classic contributions in their disciplines.

4.10 Comparing the results of the co-citation analyses for the two time periods conveys a remarkable change in the general character of the discipline's intellectual structure. During the first five years, the structure is only loosely clustered with few focal points. The most prominent and focused areas address norms, learning, evolution and methodological issues of simulation. In contrast, many new and often much more compact clusters can be identified for the second time period (see Appendix). Several changes can also be detected in the content of the discussion. A comparison of the two periods yields hardly any continuity in the clusters. This observation provides another indicator for the discipline's early stage of development and/or its dynamic character. In contrast, a high level of continuity characterizes well-established disciplines with respect to clusters and even to basic sources in these clusters over several time periods (Meyer et al. 2008). The cluster dealing with norms represents the only exception in our investigation of the two time periods. It also shows some continuity with respect to two of its sources. Apart from that, many new topics have emerged in the second period. The focus of discussion now appears to be much more centered on specific topics, e.g. on opinion dynamics, reputation and behavioral economics. This observation is in line with the results from the citation analysis showing the discipline's increasing thematic focus.

4.11 Overall, a tentative interpretation of the results from the co-citation analyses is based on the fact that a pattern of increasing focus is quite typical for the formation of scientific disciplines (Thackray and Merton 1972). It suggests that the investigation actually managed to capture social simulation both in its early stage and during its first steps towards becoming a more differentiated discipline. However, this view still requires further studies for its confirmation. Future research should especially examine two questions: (1) Can the same differentiated and focused structure be observed in subsequent time periods? (2) Do some of clusters identified in our investigation still exist in subsequent time periods?

Discussion and Conclusion

5.1 This paper aimed at mapping the intellectual structure of social simulation and its development based on the first ten years of *JASSS*. It roots in the assumption that the citations used by researchers adequately represent the intellectual basis upon which a discipline develops (Ramos-Rodriguez and Ruiz-Navarro 2004). We employed several bibliometric methods in order to accomplish our objective. In a first step, we drew upon citation analysis to identify the most influential articles and to characterize the general intellectual basis of the field. In a second step, we applied co-citation analysis enabling us to visualize the structural relationships between important sources of the field and to identify lines of research.

5.2 The results of our analyses can contribute to a better understanding for the field of social simulation in several ways. We were able to determine the most prominent publications in the social simulation discourse. The analysis suggests Axelrod to be the most influential author with three highly ranked publications over the two time periods. Epstein/Axtell (1996) and Gilbert/Troitzsch (1999) were also very prominent sources. It is remarkable that these publications rank at the top in both time periods and that they are mainly books. The strong position of books written by pioneers in their respective fields is in line with the early development of other young disciplines (Nerur et al. 2008; Ponzi 2002). From a practical perspective, the list denoting the most influential publications is potentially useful for existing simulation researchers striving to make their intellectual basis more explicit and newcomers to the field seeking some orientation alike. Moreover, the citation analysis revealed that the vast majority of cited sources were books in the first time period, while

journal publications became more important in the second time period. This is also a tendency that can be found in some other disciplines during the process of maturation (e.g. Ramos-Rodriguez and Ruiz-Navarro 2004). Finally, our analysis substantiates the much stated claim concerning the diverse and multidisciplinary nature of social simulation. Not only draws the field on an extremely diverse set of journals, but these journals, in turn, are also associated with very different disciplines such as economics, computer science, psychology, sociology or biology. Therefore, our results clearly underline the multidisciplinary character of social simulation.

5.3 The results of the co-citation analysis allowed for exploring several further important aspects concerning the intellectual structure of social simulation. We were able to identify several clear foci in the discourse of social simulation. In the first period, only a few discourse topics existed. They addressed norms, learning, evolution and methodological issues of simulation. In this time period, the co-citation network features mainly loose clusters and many of the identified groups deal with quite fundamental issues for the application of simulation in the social sciences. Contrary to that, a larger number of more compact clusters can be observed in the second time period often centering on thematically more specialized issues. Opinion dynamics, reputation and behavioral economics are examples of particularly dense clusters indicating areas of focused knowledge exchange. Once more, this pattern is typical for the further development in other young disciplines and considered a sign of a field's maturation (Nerur et al. 2008; Thackray and Merton 1972). Furthermore, some of the clusters can be related to special interest groups in ESSA. This suggests that a certain level of coherence has already been reached between the intellectual and the professional structures of the discipline (Thackray and Merton 1972). Overall, it appears to be an adequate interpretation of the results to state that they show the field of social simulation both in its early stage and during its first steps towards becoming a more differentiated and mature discipline.

5.4 As any study of this kind, this paper has limitations. First, citation studies are criticized for treating all citations alike, although publications may be cited for very different purposes ranging from support to criticism (Cronin 1984). Second, the paper focused on *JASSS* and therefore is based on only one journal. As *JASSS* is closely associated with ESSA, this was seen as a reasonable and informative first step which should be extended in the future. Interesting candidates in this respect are *CMOT* or *JEIC*. Finally, citation studies suffer from a certain time lag, as it takes some time for publications to appear and to build up a citation record. This means that the most current developments in social simulation concerning influential papers and foci of research might not be adequately reflected in the paper. For this reason, additional insights could be gained from a replication of this study in the future - possibly expanded by further analyses. It would be of particular interest to assess if some of the clusters identified in the second time period continue to exist.

5.5 Future studies might also employ other bibliometric methods such as author co-citation analysis or co-journal analysis. An investigation of social simulations impact on other disciplines might provide another fruitful avenue for future research. Finally, an attempt to reproduce the data reported here by the means of simulation (Gilbert 1997) might be worthwhile. Given the fact that much of the data has already been presented in network form, this should generally be possible. Such an endeavor seems especially promising, as it could provide additional insights not only in the development of social simulation but in the formation of new fields in general.

Notes

[1] We are aware of certain limitations that result from the initial concentration on *JASSS*. However, doing so as a first step allows for the analysis to focus on the perception of the communities of researchers that are associated with that journal, as it is perceived to be closely associated with ESSA. In a next step, it would be of interest to perform the same analysis for other journals, and then finally, integrate the results into one big picture.

[2] As Mullins et al. (1977) and McCain (1986) show, the co-citation structure is relatively reliable in comparison with the results of a survey for reflecting how involved the researchers are perceived to be. Because these networks are not necessarily formally linked, they are often referred to as "invisible colleges". See Crane (1972) and Lievrouw (1989).

[3] Following Gmür (2003), we define a threshold of 0.25 in order to focus on the strongest links.

[4] See http://jasss.soc.surrey.ac.uk. Generating the data directly also had the advantage of avoiding the typical problems associated with using the data from SSCI, such as a high percentage of errors. See Moed (2002).

[5] Similarity of two citations was defined for the HTML Parser as a match of at least to 90% between the first corresponding authors and the words in the cited text.

[6] Abbreviations: f_k = absolute frequency, p_k = relative frequency, cp_k = cumulative relative frequency.

[7] See Gilbert (1997). As mentioned above, in our study we analyse all citations with a frequency of three or more, which represent about five per cent of the whole data set.

[8] Such a tendency can have several causes, like changes in technology resulting in an easier on-line access to journals.

[9] See e.g. Ramos-Rodriguez and Ruiz-Navarro (2004) or Meyer et al. (2008).

[10] See e.g. Ramos-Rodriguez and Ruiz-Navarro (2004) or Meyer et al. (2008).

[11] The ISI journal categorization has been constructed based on journal subject content and citation information. See Klavans and Boyack (2006: 253). For a similar approach to assess the interdisciplinary breadth of a field see Ponzi (2002).

[12] To provide some more structure we subsumed related ISI subject categories in Figure 4 additionally under more general categories such as economics & management, social science and biological sciences.

[13] http://www.casos.cs.cmu.edu/projects/ora/index.html.

[14] Given *g* nodes in a cluster, there are *g (g-1) / 2* possible relationships. With *L* as the number of actual relationships, density is defined as *2L / g(g-1)*. See Iacobucci (1994:101-103). The density for the different clusters is given in the appendix.

[15] To support our decision in favor of certain designations as far as possible, we discussed them with a number of experts. Moreover, the results were presented to several international seminar and conference audiences for additional feedback.

[16] The remaining 43 publications do not exhibit any or fewer than three co-citation relationships to other sources and are therefore not included.

[17] A list of publications included in the networks is provided in the appendix. This list is structured along the different clusters and groups and can be accessed directly via the respective hyperlinks in the text.

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Accounting-Forschung: Eine Zitations- und Kozitationsanalyse englischsprachiger Accounting-Journals 1990-2004. *Zeitschrift für betriebswirtschaftliche Forschung*, Vol. 3, No. 60, pp. 153-181.

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OSAREH, F (1996a). Bibliometrics, Citation Analysis and Co-Citation Analysis I: A Review of Literature. *Libri*, Vol. 46, No. 3, pp. 149-158.

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Appendix: List of Publications

Table A1: Publications of Co-citation Network 1 (1998-2002)

Group	Publication	No. of links (within the group)
1.1 Norms (description) (picture) D = 0.56	WALKER, A and WOOLDRIDGE, M J (1995). Understanding the emergence of conventions in multi-agent systems. *Proceedings of the First International Conference on Multiagent Systems (ICMAS'95)*, San Francisco, CA: AAAI Press, pp. 384-389.	8
	SHOHAM, Y and TENNEHOLTZ, M (1992). On the synthesis of useful social laws for artificial agent societies (preliminary report). *Proceedings of the AAAI Conference,* pp. 276-281.	6
	SHOHAM, Y and TENNEHOLTZ, M (1992). Emergent conventions in multi agent systems: Initial experimental results and observations. *Proceedings of the 3rd International Conference on KR&R,* pp. 225-232.	5
	CONTE, R and CASTELFRANCHI, C (1995). Understanding the Functioning of Norms in Social Groups through Simulation. In Gilbert G N and Conte R (Ed.): *Artificial Societies: The Computer Simulation of Social Life*. London: UCL Press, pp. 252-267	4
	CASTELFRANCHI, C, CONTE, R and PAOLUCCI, M (1998). Normative Reputation and the Costs of Compliance. *Journal of Artificial Societies and Social Simulation*, vol. 1, no. 3.	4
	SAAM, N J and HARRER, A (1999). Simulating Norms, Social Inequality, and Functional Change in Artificial Societies. *Journal of Artificial Societies and Social Simulation*, vol. 2, no. 1.	4
	TRIVERS, R L (1971). The evolution of reciprocal altruism. *Quarterly Review of Biology*, Vol. 46. pp. 35-57.	4
	SCHELLING, T C (1960). *The strategy of conflict*. Oxford: Oxford University Press.	3

	HOMANS, G (1950). *The human group*. New York: Harcourt Brace.	2
1.2 Learning and Genetic Algorithms (description) (picture) D = 0.36	KOZA, J (1992). *Genetic Programming: On the Programming of Computers by Means of Natural Selection*. MIT Press, Cambridge, MA.	4
	MOSS, S and EDMONDS, B (1998). Modelling economic learning as modelling. *Cybernetics and Systems*, Vol. 29, pp. 215-247.	3
	HOLLAND, J H et al. (1986). *Induction: processes of inference, learning and discovery.* Cambridge, MA: MIT Press.	3
	ARTHUR, B W (1994). Inductive reasoning and bounded rationality. *American Economic Association Papers and Proceedings,* 84, 406-411.	3
	CONTE, R and CASTELFRANCHI, C (1995). *Cognitive and Social Action*. London: UCL Press.	2
	HOLLAND, J H (1975). *Adaptation in Natural and Artificial Systems*. University of Michigan Press.	2
	GOLDBERG, D E (1989). *Genetic Algorithms in Search, Optimization, and Machine Learning*. Addison-Wesley.	2
	OLSON, M (1965). *The Logic of Collective Action.* Cambridge, MA: Harvard University Press.	1
1.3a Paradigmatic Issues of Economics and Social Simulation (description) (picture) D = 0.27	GILBERT, N and CONTE R (1995). *Artificial Societies: the computer simulation of social life*. London: UCL Press.	5
	HODGSON, G M and GEOFFREY M (1988). *Economics and Institutions: A Manifesto for a Modern Institutional Economics*. Cambridge, MA: Polity Press.	4
	ORMEROD, P (1995). *The Death of Economics.* London: Faber and Faber.	3
	ORMEROD, P (1998). *Butterfly Economics.* London: Faber and Faber.	3
	ARTHUR, W B, DURLAUF S N and LANE D A (1997). *The Economy as an Evolving Complex System II*. Reading, MA: Addison-Wesley.	3
	GILBERT N (1995). Emergence in social simulation. In Gilbert G N and Conte R (Ed.): *Artificial Societies: The Computer Simulation of Social Life*. London: UCL Press, pp. 144-156.	2
	MACY, M W (1998). Social Order in Artificial Worlds. *Journal of Artificial Societies and Social Simulation*, Vol. 1, No. 1.	1
	ARTHUR, WB (1994). *Increasing Returns and Path Dependence in the Economy*. Ann Arbor, MI: University of Michigan Press.	1
	GOLDSPINK, C. (2000). Modelling Social Systems as Complex: Towards a Social Simulation Meta-model. *Journal of Artificial Societies and Social Simulation,* Vol. 3, No.2.	1
	WOOLDRIDGE, M and JENNINGS, N (1995). Intelligent agents: Theory and practice. *The Knowledge Engineering Review*, Vol. 10, No. 2, pp. 115-152.	1
1.3b Methodological Aspects of Social Simulation (description) (picture) D = 0.38	GILBERT, G N and TROITZSCH, K G (1999). *Simulation for the Social Scientist*. Buckingham: Open University Press.	4
	TROITZSCH, K G (1997). Social science simulation - Origins, prospects, purposes. In Conte, R et al. (Eds) *Simulating social phenomena*. Heidelberg: Springer, pp. 40-54.	4
	CONTE, R, HEGSELMANN, R and TERNA, P (1997). Introduction: Social simulation - A new disciplinary synthesis. In Conte R, Hegselmann R and Terna P (Ed.): *Simulating social phenomena*. Heidelberg: Springer, pp. 1-17.	3
	HANNEMAN, R A (1995). Simulation modeling and theoretical analysis in sociology. *Sociological Perspectives*, Vol. 38, No. 4, pp. 457-462.	2
	NOWAK, A and LEWENSTEIN, M (1996). Modeling social change with cellular automata. In Hegselmann R, Mueller U, Troitzsch K G (Ed.): *Modelling and Simulation in the Social Sciences from the Philosophy of Science Point of View*. Berlin: Springer, pp. 249-285.	1
	KAUFFMAN, S A (1993). *The Origins of Order: Self-*	1

	Organization and Selection in Evolution. New York: Oxford University Press.	
	AXELROD, R (1997). Advancing the Art of Simulation in the Social Sciences. In Conte R, Hegselmann R and Terna P (Ed.): *Simulating Social Phenomena*. Berlin: Springer	1
1.4 Psychology / Economics and Technology (description) (picture) D = 0.25	DAVID, P A (1985). Clio and the Economics of QWERTY. *American Economic Review,* Vol. 75, pp. 332-337.	4
	FESTINGER, L (1954). A theory of social comparison processes. *Human Relations*, Vol. 7, pp. 117-140.	3
	MASLOW, A H (1954). *Motivation and Personality*. New York: Harper and Row.	2
	ARTHUR, B (1989). Competing Technologies, Increasing Returns, and Lock-In by Historical Events. *Economic Journal,* Vol. 99, pp. 116-131.	2
	SCHUMPETER, J (1934). *The Theory of Economic Development*. Cambridge, MA: Harvard University Press.	2
	NELSON, R and WINTER, S (1982). *An Evolutionary Theory of Economic Change*. Cambridge, MA: Belknap Press of Harvard University Press.	2
	BANDURA, A (1977). *Social Learning Theory*. Englewood Cliffs, New Jersey: Prentice Hall.	1
	ARROW, K J (1962). The Economic Implications of Learning-by-doing. *Review of Economic Studies,* Vol. 29, pp.155-73.	1
	ARTHUR, W B (1988). Competing Technologies: An Overview. In Dosi G, Freeman C, Nelson R, Silverberg G and Soete L (Ed.): *Technical Change and Economic Theory*. London: Pinter, pp. 590-607.	1
2 Evolutionary Perspective (description) (picture) D = 0.50	BOYD, R and Richerson, P (1985). *Culture and the evolutionary process*. Chicago: Chicago University Press.	3
	HOLLAND, J H (1998). *Emergence: from chaos to order*. Reading, MA: Addison Wesley.	3
	DENNETT, D (1995). *Darwin's Dangerous Idea*. New York: Simon & Schuster.	2
	DAWKINS, R (1976). *The Selfish Gene.* Oxford: Oxford University Press.	1
	AXTELL, R (2000). Why agents? On the varied motivations for agent computing in the social sciences. *Center for Social and Economic Dynamics*, Working Paper No. 17.	1

Table A2: Publications of Co-citation Network 2 (2003-2007)

Group	**Publication**	**No. of links (within the group)**
1.1 Networks and Diffusion (description) (picture) D = 0.43	KUPERMAN, M and ABRAMSON, G (2001). Small World Effect in an Epidemiological Model. *Physical Review Letters*, Vol. 86, No. 13, pp. 2909-2912.	4
	NEWMAN M E J (2002). Spread of epidemic disease on networks. *Physical Review E*, Vol. 66(1 Pt 2). 016128.	4
	WATTS, D J and STROGATZ, S H (1998). Collective Dynamics of 'Small world' Networks. *Nature*, Vol. 393, No. 6684, pp. 440-442.	3
	WATTS, D J and DUNCAN, J (1999). *Small Worlds: The Dynamics of Networks between Order and Randomness*. Princeton, NJ: Princeton University Press.	2
	COWAN, R and JONARD, N (2004). Network structure and the diffusion of knowledge. *Annual Review of Psychology*, Vol. 55, pp. 591-621.	2
	ALBERT, R and BARABSI, A L (2002). Statistical Mechanics of Complex Networks. *Review of Modern Physics,* Vol. 74, pp. 47-97.	2
	HUANG C Y, SUN C T, HSIEH J L, and LIN H (2004). Simulating SARS: Small-World Epidemiological Modelling and Public Health Policy Assessments. *Journal of Artificial Societies and Social Simulation*, 2004, Vol. 7, No. 4.	1

1.2a Modeling Pitfalls (description) (picture) D = 0.56	POLHILL, J G, IZQUIERDO, L R and GOTTS, N M (2005). What every agent based modeller should know about floating point arithmetic. *Environmental Modelling and Software.* Vol. 21, pp. 283-309.	9
	POLHILL J G, IZQUIERDO, L R and GOTTS, N M (2005). The ghost in the model (and other effects of floating point arithmetic). *Journal of Artificial Societies and Social Simulation*, Vol. 8, No. 1.	8
	LEBARON, B, ARTHUR, W B and PALMER, R (1999). Time series properties of an artificial stock market. *Journal of Economic Dynamics and Control*, Vol. 23, pp. 1487-1516.	7
	GOTTS, N M, POLHILL, J G and LAW, A N R (2003). Aspiration levels in a land-use simulation. *Cybernetics and Systems*, Vol. 34, pp. 663-683.	6
	POLHILL, J G, GOTTS, N M and LAW, A N R (2001). Imitative versus nonimitative strategies in a land use simulation. *Cybernetics and Systems,* Vol. 32, pp. 85-307.	6
	HIGHAM, N J (2002). *Accuracy and Stability of Numerical Algorithm. 2nd ed*. Philadelphia: Society for Industrial and Applied Mathematics.	5
	IEEE (1985). *IEEE Standard for Binary Floating-Point Arithmetic*. New York, NY: Institute of Electrical and Electronics Engineers.	5
	JOHNSON, P E (2002). Agent-Based Modeling: What I learned from the Artificial Stock Market. *Social Science Computer Review*, Vol. 20, pp. 174-186.	5
	KNUTH, D E (1998). *The Art of Computer Programming. Third Edition*. Boston, MA: Addison-Wesley.	5
	AXELROD, R (1986). An Evolutionary approach to norms. *American Political Science Review*, Vol. 80, No. 4, pp. 1095-1111.	3
	GALAN J M and IZQUIERDO L R (2005). Appearances can be deceiving: Lessons learned re-implementing Axelrod's 'Evolutionary Approach to Norms'. *Journal of Artificial Societies and Social Simulation,* Vol. 8, No. 3.	3
1.2b Model Alignment (description) (picture) D = 0.40	EDMONDS B and HALES D (2003). Replication, replication and replication: Some hard lessons from model alignment. *Journal of Artificial Societies and Social Simulation*, Vol. 6, No. 4.	2
	AXTELL R, AXELROD R, EPSTEIN J and COHEN, M D (1996). Aligning Simulation Models: A Case Study and Results. *Computational and Mathematical Organization Theory*, Vol. 1, No. 1, pp. 123-141.	2
	HALES D, ROUCHIER J and EDMONDS B (2003). Model-to-Model Analysis. *Journal of Artificial Societies and Social Simulation,* Vol. 6, No. 4.	2
	CARLEY K M, PRIETULA M J and LIN Z (1998). Design Versus Cognition: The interaction of agent cognition and organizational design on organizational performance. *Journal of Artificial Societies and Social Simulation*, Vol. 1, No. 3	2
	CARLEY K M (1992). Organizational Learning and Personnel Turnover. *Organization Science*, Vol. 3, No. 1, pp. 20-46.	1
1.2c (undescribed branch) (picture)	EPSTEIN J M and Axtell R L (1996) *Growing Artificial Societies: Social Science from the Bottom Up*. Washington D.C.: The Brookings Institution Press and Cambridge, Mass.: The MIT Press.	3
	CONTE R, EDMONDS B, SCOTT M, SAWYER R K (2001). Sociology and Social Theory in Agent-Based Social Simulation: A Symposium. *Computational and Mathematical Organization Theory*, Vol. 7, pp. 183-205.	2
	PARKER, M (2000). *Ascape: Abstracting Complexity*. Swarmfest Proceedings.	1
	ZEIGLER B P (1976). *Theory of Modelling and Simulation*. New York: John Wiley.	1
	CONTE R and CASTELFRANCHI C (1995). *Cognitive and Social Action*. London: UCL Press.	1

1.3a Diffusion and Social Networks (description) (picture) D = 0.67	GRANOVETTER, M (1985). Economic Action and Social Structure: The problem of embeddedness. *American Journal of Sociology*, Vol. 91, No. 3, pp. 481-510.	6
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2.1 Reputation (description) (picture) D = 0.42	KREPS, D M and WILSON, R (1982). Reputation and Imperfect Information. *Journal of Economic Theory*, Vol. 27, pp. 253-279.	6
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3 Opinion Dynamics (description) (picture) D = 0.32	HEGSELMANN, R and KRAUSE, U (2002). Opinion Dynamics and Bounded Condence Models, Analysis and Simulation. *Journal of Artificial Societies and Social Simulation*, Vol. 5, No 3.	11
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4 Environmental Aspects and Resource Use (description) (picture) D = 0.19	VINCK, D (1999). Les objets intermédiaires dans les réseaux de coopération scientifique. *Revue Française de Sociologie*, Vol. 40, pp. 385-414.	5
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5b (undescribed branch) (picture)	PARSONS, T (1951). *The Social System*. New York: Free Press.	2
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6 Behavioral Economics / Artificial Markets (description) (picture) D= 0.24	AXTELL, R (2000). *Why agents? On the varied motivations for agent computing in the social sciences.* Center for Social and Economic Dynamics, Working Paper No. 17.	6
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7 Evolution and Learning in Social Dilemmas (description) (picture) D = 0.29	DAWES, R M (1980). Social Dilemmas. *Annual Review of Psychology*, Vol. 31, pp. 161-193.	3
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