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Measuring CMOT's intellectual structure and its development

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Abstract Computational Organization Theory is often described as a multidisciplinary and fast-moving field which can make it difficult to keep track of it. The recent inclusion of *Computational and Mathematical Organization Theory* (CMOT) into the Social Science Citation Index offers a good reason to take stock of what has happened since the foundation of the journal and to analyze its intellectual structure and development from 1995 to 2008. We identify the most influential publications by means of citation analysis and show that a core of codified knowledge has developed over time. Additionally, we provide empirical support for the characteristics generally ascribed to the journal such as multidisciplinarity. Finally, we depict the main research foci in CMOT's intellectual structure employing a co-citation analysis of publications and investigate their development over time. Overall, our quantitative review shows CMOT to be thematically focused on organizations, groups and networks while being remarkably diverse in terms of theoretical approaches and methods used.

Keywords Citation analysis · Co-citation analysis · Computational organization theory · Multidisciplinarity · Research foci · Sociology of science

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1 Introduction

The recent inclusion of *Computational and Mathematical Organization Theory* (CMOT) into the Social Science Citation Index marks just the latest step in the notable development of the journal and the intellectual communities related to it. The field emerged in the late eighties from small workshops of about ten participants that brought together researchers from artificial intelligence with organizational psychologists and sociologists. It was initially established as a special interest group within TIMS and ORSA (now INFORMS) before being further institutionalized by the foundation of NAACSOS, its professional association (Samuelson 2000). Parallel to this development, the journal CMOT was founded in 1995 providing a specialized publication outlet for the new research area (Carley and Wallace 1995). The field has expanded even further since then. It now goes "far beyond its earlier boundaries, to link up with other groups of people and encompass work in a range of disciplines including computer science, artificial intelligence, economics, sociology, physics, biology, anthropology and even archaeology" (Samuelson and Macal 2006, p. 35).

Although the field's steady growth and its dynamic, multidisciplinary character are welcome, they make it increasingly difficult to obtain an overview of the field and its development at the same time. This bears several risks. First, for researchers active in one specific area, there may be a tendency to view the field from their particular perspective. This can not only introduce a certain bias, but, even more importantly, also poses the danger of missing important developments. Secondly, a lack of overview can raise the costs of entry into the field as it may seem too complex for newcomers and, thus, very challenging to identify promising possible points of contact. Finally, there is not enough reliable empirical information available right now to allow for comparisons with other communities or disciplines. This prevents researchers from drawing conclusions about the field's position within the scientific landscape.

In an attempt to overcome this current situation, it is the objective of this paper to investigate the intellectual structure of CMOT and its development. Based on all articles published in CMOT between 1995 and 2008, we analyze a specially created data set of 216 articles and 7,953 citations by means of citation and co-citation analysis. This enables us to identify the most influential publications in CMOT and, consequently, to assess whether an accepted core of literature exists for the field. We also investigate the main characteristics of citations in CMOT and examine the supposedly multidisciplinary character of the journal. Finally, we identify the main research foci within its intellectual structure and analyze their development over time. Where suitable, we compare our results to other bibliometric studies in order to position both CMOT and the community related to it within the scientific landscape.

The remainder of the paper is organized as follows. In the next section, we outline our theoretical perspective, review extant literature and develop our research questions. After describing our method and the generation of our data set, we present the results of the citation analysis with an emphasis on two aspects: the most influential publications and the disciplinary origin of the sources used in CMOT. Subsequently, co-citation analysis is used to identify the main research foci and to investigate their development over time. Finally, we discuss the overall picture resulting from our quantitative review of research in CMOT and provide a brief conclusion.

2 Literature review and research questions

In this paper, we investigate CMOT's intellectual structure and its development. As we apply bibliometric methods, the paper's approach can be classified as a quantitative study of science which, in turn, represents a subfield of the sociology of science.[1] Important theoretical and methodological foundations to the sociology of science were laid by the sociologist Robert K. Merton. He introduced several important theoretical concepts to the discussion and investigated them empirically (Merton 1979). Of special interest for this study is his idea of knowledge codification that he introduced together with Harriet Zuckerman (Merton and Zuckerman 1972). They argue that scientific fields differ in the extent to which they are codified, i.e. the level of consensus varies from field to field. They measured the level of consensus via rejection rates for scientific journals. Subsequently, Cole (1983) pointed out that, with respect to knowledge codification, two types of knowledge have to be distinguished in a discipline: a stable core of codified knowledge and a frequently changing research front. While "the core consists of a small set of theories and analytic techniques which represent the 'given' at any particular point in time" (Cole 1983, p. 113), the research frontier is the place "where all new knowledge is produced" (Cole 1983, p. 113). According to Cole, one can expect high levels of consensus at the core of established scientific fields while the level of consensus is substantially lower across all disciplines at the research front (Cole 2004). To characterize CMOT and the intellectual community related to it, it would be helpful to know whether such a core has developed and, if this is the case, which publications form this core. This would allow for an assessment of the field in terms of maturity and content.

Merton's work is usually considered to be part of the functionalist tradition and has been criticized for leaving the cognitive content of science out of sociological investigation (Prus 1996). The so-called new sociology of science considers this component more explicitly when addressing the social dimension and structure of science. It has been influenced by the works of authors such as Thomas S. Kuhn and Harold Garfinkel (Prus 1996). Kuhn is particularly noteworthy as his notion of paradigms and their dramatic shifts caused by scientific revolutions (Kuhn 1970) represents one of the most prominent concepts regarding the structure of scientific disciplines. But structures can also be found within disciplines and fields. In this context, Crane (1972) coined the term "invisible colleges" for networks of researchers who are not necessarily formally linked but adhere to the same approach and/or topic. Alternatively, one can dissect the intellectual structure of a scientific field by identifying relationships between publications (Gilbert 1997). This perspective is frequently used in order to provide a more detailed map of a field's intellectual structure (Charvet et al. 2008; Ramos-Rodriguez and Ruiz-Navarro 2004). With respect to CMOT, analyzing the relationships between publications would allow for assessing the level of differentiation within field and

[1] The application of quantitative methods to the study of science has been fostered by the Institute for Scientific Information (ISI) founded in 1960 by Eugene Garfield. Among the available data bases, the Social Science Citation Index (SSCI) is particularly relevant for the social sciences and economics as it provides digital citation data for the publications in leading scientific journals.

for identifying possible foci of research. The resulting quantitative findings would not only complement existing qualitative descriptions of the field (Carley 1995; Samuelson 2000), they would also allow for an objective comparison with the intended aim and scope of the journal (Carley and Wallace 1995).

Currently, several citation and co-citation studies exist that investigate the intellectual structure of scientific disciplines (Charvet et al. 2008; Nerur et al. 2008). However, we are not aware of any such study for the field of computational organization theory. The study by Ashworth and Carley (2007) comes closest in reviewing organizational simulation modeling. They show that there is a steady increase of models with agent behavior that is dynamic, adaptive, more realistic and embedded in network settings. Another point of reference is provided by Meyer et al. (2009). Their study of the intellectual structure of the *Journal for Artificial Societies and Social Simulation* (JASSS) informs about the field of social simulation. The journal shares the computational perspective on social phenomena with CMOT, but focuses less on organizations and related phenomena. The study on JASSS provides evidence that social simulation is evolving into a mature and established scientific field. In particular, it identifies a core of basic sources representing the codified knowledge in the field and shows that its intellectual structure—as reflected in its research foci—has become more focused and specialized. Moreover, the suggested multidisciplinary nature of the field could be clearly supported. Drawing upon those existing findings, a bibliometric study of CMOT would not only generate empirical information about the field's intellectual structure and development, but would also allow for comparing between the US-based journal CMOT and the European-based journal JASSS.[2]

Based on the theoretical perspective described and extant literature, we suggest the following research questions as a focus for our subsequent analyses: (1) Which are the most influential publications in CMOT and has an accepted core of codified literature emerged in the field? (2) What are the main characteristics of citations in CMOT and to what extent does the field encompass a broad range of multidisciplinary research as suggested both by the journal and observers of the field (Samuelson and Macal 2006)? (3) What are the main research foci in CMOT and what developments have occurred over time? The results are compared to the recently conducted bibliometric study of JASSS. This enables us to identify similarities and possible differences between the journals and the communities related to them.

3 Method and Data Set

The two methods used in this study are citation and co-citation analysis (see Fig. 1). Both are well-established bibliometric methods for analyzing the structures of scientific disciplines (Osareh 1996a, 1996b). Citation analyses investigate the relationships between citing and cited publications. A citation is interpreted as a measure of the importance attached to the source or its author in the respective publication. This method is well-suited for the identification of influential publications addressed by our first

[2]Still, one should note that both journals—CMOT and JASSS—attract contributions from a broad range of countries meaning that European authors also publish in CMOT and vice versa.

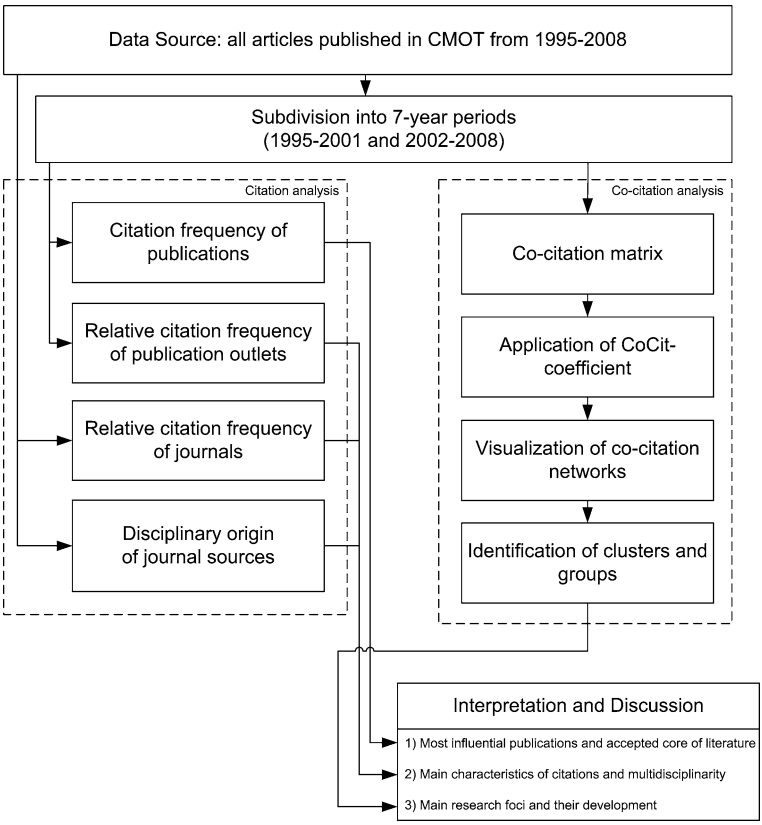

Fig. 1 Design of the empirical study

question (Small 1978). Our second research question regarding the citations' main characteristics and multidisciplinary character can be approached by analyzing the characteristics of all the citations in a data set, e.g. with respect to their disciplinary origin, making citation analysis the method of choice as well (Tempest 2009).

Co-citation analyses examine the relationships between several cited publications. This allows us to draw conclusions about the internal structure of research and the existing research foci (Chen and Paul 2001; Small 1980), our third research question. A co-citation exists between two publications or researchers when they are cited in the same source document, i.e. when two publications, respectively researchers are listed in the same bibliography. The number of co-citations is interpreted as a measure for the proximity of the sources or their authors. Co-citation analysis is used to derive the underlying structure of a field and, thereby, to incorporate "the empirical consensus of hundreds of citers rather than the impressions of individuals" (Lunin and White 1990, p. 430). It is important to note that the derived networks are not groups of individuals that are actually linked, for example through working for the same institution, but groups of publications that are perceived as being related. As Mullins et

al. (1977) and McCain (1986) show, the co-citation structure reflects rather reliably how involved the researchers are perceived to be compared to the results of a survey.[3]

Co-citation research embraces a large number of different methods to determine co-citation clusters. For the purposes of the present study, we chose a network-based method because comparable studies used it successfully for identifying distinctive and sharply defined clusters (Ahlgren et al. 2003; Gmür 2003; Meyer et al. 2009). Moreover, to track the field's development, we define two time periods of seven years each that are analyzed subsequently: Period 1 (1995–2001) and Period 2 (2002–2008).

The analysis focuses on the most-cited publications in order to reduce complexity (Chen and Paul 2001; Gmür 2003). To allow for a comparison with the study of JASSS conducted by Meyer et al. (2009), the co-citation analysis includes every source that was cited in at least three CMOT articles during the respective time period. The number of sources remaining is 136 for Period 1 and 166 for Period 2.

Absolute citation values, however, are not suitable for generating clearly defined clusters. Due to their wide dissemination, the most-cited sources tend to be co-cited more frequently than sources that are cited less often, even though the latter might be more closely related in terms of content. Therefore, the absolute co-citation value for two sources must be put in an appropriate relation to the frequency of citation. The so-called CoCit score is well-suited for this (Gmür 2003). The relative co-citation value for the two sources A and B is scaled to a range between 0 and 1 and can be calculated using the following formula:

$$CoCit_{AB} = \frac{(co\text{-}citation_{AB})^2}{Minimum(citation_A; citation_B) \times Mean(citation_A; citation_B)}$$

The strongest co-citation relationships are selected based on their CoCit score for our study.[4] The resulting co-citation networks comprise several clusters that can take the form of isolated pairs, co-citation chains, co-citation stars, or a number of groups of different sizes that are interlinked. In this paper, we describe a group as a cluster when it has at least three sources that are linked by at least three strong co-citation relationships and at least one node that has more than two edges.

The data set for this study is based on articles published in CMOT between 1995 and 2008.[5] The resulting set of 216 publications to be included appears to be clearly

[3]Possible limitations and biases of co-citation analyses are discussed in Hicks (1987, 1988) and in the reply by Franklin (1988). As our study focuses on one specific journal, it is not affected by biases that are introduced by differences in the length of reference lists found between journals and possibly favor certain specialties or topics. Still, some of the standard limitations of citation and co-citation analyses apply to this study as well, like a certain time delay and some unavoidable subjective elements (Ramos-Rodriguez and Ruiz-Navarro 2004). Furthermore, such studies only cover published work and treat all citations alike, although publications may be cited for very different purposes ranging from support to criticism (Cronin 1984).

[4]Following Gmür (2003), we define a threshold (0.3) in order to focus on the strongest links. We tested the robustness and the discrimination power of this threshold. With respect to our aim to identify the main research foci, other thresholds in the range between 0.25 and 0.33 lead to comparable results. In addition, we compared the discrimination power for different thresholds by comparing the number of links in the network and identified 0.3 as the most suitable threshold for the two time periods.

[5]Like other comparable bibliometric studies, we excluded editorials, book reviews and similar material.

Table 1 Data set

	Period 1: 1995–2001			Period 2: 2002–2008			Σ
Number of citations	3,543			4,410			7,953
Number of CMOT articles	97			119			216
Average number of citations per article	36.5			37.1			–
Frequency of citations in CMOT (x_k)	f_k	p_k	cp_k	f_k	p_k	cp_k	
1	2,391	86.4%	86.4%	3,067	86.8%	86.8%	
2	240	8.7%	95.1%	301	8.5%	95.3%	
3	64	2.3%	97.4%	78	2.2%	97.5%	
4	20	0.7%	98.1%	36	1.0%	98.5%	
5	17	0.6%	98.7%	26	0.7%	99.3%	
≥6	35	1.3%	100.0%	26	0.7%	100.0%	
Number of different citation sources	2,767			3,534			
Average source age in years		12.2			13.1		

Abbreviations: f_k = absolute frequency, p_k = relative frequency, cp_k = cumulative relative frequency

defined and does not have to be identified through steps such as a keyword search in a wide range of publication outlets. Still, we encountered several problems when preparing our data set. First, CMOT articles and their reference lists are currently only partially covered in the database Scopus (starting from 2005). Knowing that databases are frequently reported to have substantial shares of incorrectly entered data (Moed 2002) and being unwilling to mix two data sources, we decided to enter all data by hand. This ensured a high level of data quality and consistency in particular. Second, given the fact that not all references were entered homogenously by the authors, we also checked whether citations referring to the same publication were noted as identical. Although this procedure proved to be time consuming, we considered it as an important precondition to be fulfilled in order to receive reliable results (Hicks 1987). Table 1 gives an overview of the resulting data set.

Before we discuss the results of the citation and co-citation analysis, the data set is briefly characterized. First, it is important to note that the number of articles published in CMOT has increased over time. Although this leads to an increase 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 almost unchanged. Second, most citations occur once or twice in CMOT with only a few publications displaying higher citation frequencies. This power law distribution is a typical pattern found in many bibliometric studies and allows for focusing on the most-cited publications for

co-citation analysis.[6] Third, the average source age amounts to 12.2 years for Period 1 and to 13.1 years for Period 2. This is relatively high compared to the average source age of four years in the natural sciences, but represents yet again a typical value found in comparable studies for many areas of the social sciences (Bricker 1988).

Compared to JASSS, both the average number of citations and the average source age are higher in CMOT. In JASSS, the average number of citations is 26.1 (1998–2002) and 29.2 (2003–2007) respectively and the average source age is constant at approximately eleven years (Meyer et al. 2009). One possible explanation for these discrepancies is the difference in research traditions between the communities publishing in the respective journals. Particularly in organization science and sociology, it might be more typical to review the field extensively (also including classic publications) resulting both in more citations and a higher average source age. This is one of the topics to be addressed in our next section that presents the results of our citation analysis.

4 Citation analysis results

We employ citation analysis in two steps of our research: for determining the most influential publications and for testing if the results regarding the publication outlets and their disciplinary origin extend from the most-cited sources to the entire data set. First, we use citation analysis to identify the most influential publications in the field. The results for both time periods are presented in Table 2 listing the most-cited sources and their outlets (book or journal, giving the name for the journals).[7] Additionally, we provide the citation value (Cit Val) which is the total number of citations divided by the total number of analyzed CMOT articles for the respective time period. The gray fields in the table indicate that the source is a top-cited publication in both time periods and can, therefore, be assumed to belong to the field's codified knowledge.

Looking at Period 1 reveals that many publications generally considered as classics in organization theory can be found among the most-cited sources. Furthermore, the high citation value of the most-cited source, Thompson (1967), is remarkable; it can be found in more than every sixth publication. The observed tendency to cite particular publications that deal with organization issues also holds true for the remainder of the most-cited sources in Period 1 complemented by some sources addressing social network analysis. Concerning the publication outlet, the list contains a more or less equal share of books/book chapters (59.2%) and journal publications (40.8%).

In Period 2, March and Simon's book (1958) trades spots with Thompson (1967) at the top. Overall, 14 publications of the previous period are among the most-cited sources (61.5%) in Period 2 as well indicating a core of codified knowledge for the field. It consists of classic contributions to organization theory, sociology and network theory. Furthermore, a core of specific sources belonging directly to the field

[6] As mentioned before, our co-citation analysis includes all citations with a frequency of three or more representing approximately 5% of the entire data set.

[7] These are the top 20 constrained by a limit of at least 5% citation frequency in CMOT.

Table 2 Most-cited sources for the two time periods

Period 1: 1995–2001				Period 2: 2002–2008			
Rank	Source	Outlet	Cit Val	Rank	Source	Outlet	Cit Val
1	Thompson J (1967) Organizations in action	Book	17.5%	1	March J, Simon H (1958) Organizations	Book	11.8%
2	March J, Simon H (1958) Organizations	Book	16.5%	2	Thompson J (1967) Organizations in action	Book	10.1%
3	Galbraith J (1977) Organization design	Book	14.4%		Coleman J (1990) Foundations of social theory	Book	10.1%
4	Scott R (1987) Organizations: Rational, natural, and open systems	Book	13.4%	4	Burt R (1992) Structural holes	Book	9.2%
5	Carley KM (1992) Organizational learning and personnel turnover	Organ Sci	12.4%		Burton R, Obel B (1995) Strategic organization diagnosis and design: Developing theory for application	Book	9.2%
	Coleman J (1990) Foundations of social theory	Book	12.4%		Carley KM (1991) A theory of group stability	Am Soc Rev	9.2%
	Cyert R, March J (1963) A behavioral theory of the firm	Book	12.4%		Epstein J, Axtell R (1996) Growing artificial societies	Book	9.2%
	Malone T (1987) Modeling coordination in organizations and markets	Manag Sci	12.4%		Lawrence P, Lorsch J (1967) Organization and environment	Book	9.2%
9	Cohen M, March J, Olsen J (1972) A garbage can model of organizational choice	Adm Sci Q	11.3%	9	Axelrod R (1997) The complexity of cooperation: Agent-based models of competition and collaboration	Book	8.4%
10	Burt R (1992) Structural holes	Book	10.3%		Carley KM (1995) Computational and mathematical organization theory: Perspective and directions	CMOT	8.4%
	Carley KM, Svoboda D (1996) Modeling organizational adaptation as a simulated annealing process	Soc Meth Res	10.3%		Carley KM, Svoboda D (1996) Modeling organizational adaptation as a simulated annealing process	Soc Meth Res	8.4%
	Wasserman S, Faust K (1994) Social network analysis: Methods and applications	Book	10.3%		Jin Y, Levitt R (1996) The virtual design team: A computational model of project organizations	CMOT	8.4%

Table 2 (*Continued*)

Period 1: 1995–2001				Period 2: 2002–2008			
Rank	Source	Outlet	Cit Val	Rank	Source	Outlet	Cit Val
13	Axelrod R (1984) The evolution of cooperation	Book	9.3%		March J (1991) Exploration and exploitation in organizational learning	Organ Sci	8.4%
	Carley KM (1995) Computational and mathematical organization theory: Perspective and directions	CMOT	9.3%	14	Burton R, Obel B (1995) The validity of computational models in organization science: From model realism to purpose of the model	CMOT	7.6%
	Hannan M, Freeman J (1977) The population ecology of organizations	Am J Soc	9.3%		Galbraith J (1977) Organization design	Book	7.6%
	Levitt R, Cohen G, Kunz J, Nass C, Christiansen T, Jin Y (1994) The virtual design team: Simulating how organization structure and information processing tools affect team performance	Book Chapter	9.3%		Kauffman S (1993) Origins of order: Self-organization and selection in evolution	Book	7.6%
17	Burton R, Obel B (1995) The validity of computational models in organization science: From model realism to purpose of the model	CMOT	8.2%	17	Wasserman S, Faust K (1994) Social network analysis: Methods and applications	Book	6.7%
	Carley KM (1991) A theory of group stability	Am Soc Rev	8.2%	18	Granovetter M (1985) Economic action and social structure: The problem of embeddedness	Am J Soc	5.9%
	Carley KM, Prietula M (eds) (1994) Computational organization theory	Book (Ed.)	8.2%	19	Carley KM, Lin Z (1997) A theoretical study of organizational performance under information distortion	Manag Sci	5.0%
	Jin Y, Levitt R (1996) The virtual design team: A computational model of project organizations	CMOT	8.2%		Cyert R, March J (1963) A behavioral theory of the firm	Book	5.0%
	Lawrence P, Lorsch J (1967) Organization and environment	Book	8.2%		DiMaggio P, Powell W (1983) The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields	Am Soc Rev	5.0%

Table 2 (*Continued*)

Period 1: 1995–2001				Period 2: 2002–2008			
Rank	Source	Outlet	Cit Val	Rank	Source	Outlet	Cit Val
	March J (1991) Exploration and exploitation in organizational learning	Organ Sci	8.2%		Galbraith J (1973) Designing complex organizations	Book	5.0%
					Granovetter M (1973) The strength of weak ties	Am J Soc	5.0%
					Roth A, Erev I (1995) Learning in extensive-form games: Experimental data and simple dynamic models in the intermediate term	Game Econ Behav	5.0%
					Simon H (1947) Administrative behavior	Book	5.0%
					Sterman J (1994) Learning in and about complex systems	Syst Dyn Rev	5.0%

emerges (e.g. Carley and Svoboda 1996 or Burton and Obel 1995); they deal with methodological issues or provide exemplary applications. Their existence might explain why some previously top-cited sources, including Scott (1987), Carley (1992) and Malone (1987), disappeared from the list. Regarding content, the focus continues to be put on organizational issues complemented by publications dealing with sociology and social network analysis. The equal distribution of books/book chapters (58.4%) and journal publications (41.6%) has remained stable.

Comparing these results with the citation analysis conducted for JASSS discloses two interesting differences. First, only a small overlap between the most-cited sources can be identified for the two journals despite covering the same subject area. The only publications to be found in both lists are Axelrod (1984, 1997), Epstein and Axtell (1996) and Kauffman (1993). Second, there was a strong dominance of books on the most-cited list for JASSS in Period 1 that decreased in Period 2. This development was considered as a sign of differentiation and maturation in the field (Meyer et al. 2009). CMOT shows a balanced outlet distribution for both periods.

In the second step using citation analysis, we tested whether the observation concerning the constantly high importance of journals holds true for the whole data set. For this purpose, we classified the sources as journal publications, books, book chapters, etc. and calculated the share of the different categories. Figure 2 shows the results for the two time periods.

The results underline the importance of journals for both time periods. Only minor changes are noticeable, such as a small decrease in journal articles in favor of an

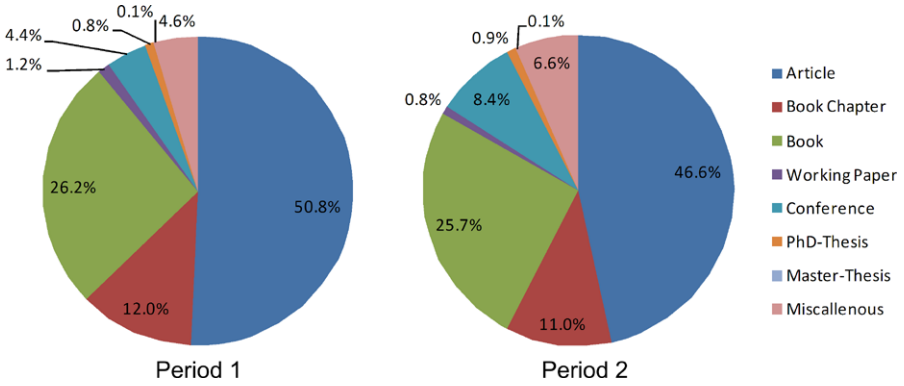

Fig. 2 Publication outlets in both periods

increase in conference proceedings and of the miscellaneous category.[8] A similar analysis for JASSS showed a significant increase in journal publications from 36.9% to 47.9% at the expense of a significant decrease in books and book chapters from 44.4% to 32.2% (Meyer et al. 2009).

Additionally, we analyzed which journals and, therefore, which disciplines matter the most for CMOT authors. Figure 3 shows the most-frequently cited journals in CMOT for the entire period of investigation.[9]

The distribution of journals illustrates that publications in CMOT draw upon a diverse set of journals. This diversity is remarkable as many other research fields are dominated by only a few journals. The most-cited journal is *Administrative Science Quarterly* with a share of 5.9%. The next most-cited journals are: *Management Science*, *CMOT* itself, *Organization Science*, *American Journal of Sociology*, *American Sociological Review*, *Social Networks*, *Journal of Mathematical Sociology*, *Academy of Management Journal*, *Academy of Management Review*, *Strategic Management Journal*, *American Economic Review* and *Annual Review of Sociology*. Each of them has a share of at least 1%. The results provide another clear indication for the journal's thematic focus.

To better understand the CMOT community we compare which journals are most cited by CMOT and JASSS. The analysis of JASSS detects a similarly diverse set of journals (Meyer et al. 2009). Besides JASSS itself at the top, it finds a set of journals such as *Nature*, *American Economic Review*, *Science*, *American Journal of Sociology*, *Physical Review*, *Physica*, *Artificial Intelligence*, *American Sociological*

[8] We tested the differences for statistical significance. The changes were supported by the results of the χ^2-test (all three categories $p < 0.001$).

[9] To allow for a comparison with Meyer et al. (2009), we present the results for the entire period of investigation. We also compared the shares of journals (and disciplines) for the two time periods. Overall, the basic patterns concerning the structure of journals and the multidisciplinary nature (see Fig. 4) of CMOT remain stable. Worth mentioning is, first, that CMOT becomes the most cited journal in the second period (5.2%), while it ranked sixth in the first (3.5%). Second, we found decreases in the shares of sociology (from 16.6% to 12.4%) and economics (from 11.7% to 3.5%). The changes in sociology and economics are supported by the results of a χ^2-test (both categories are significant $p < 0.001$).

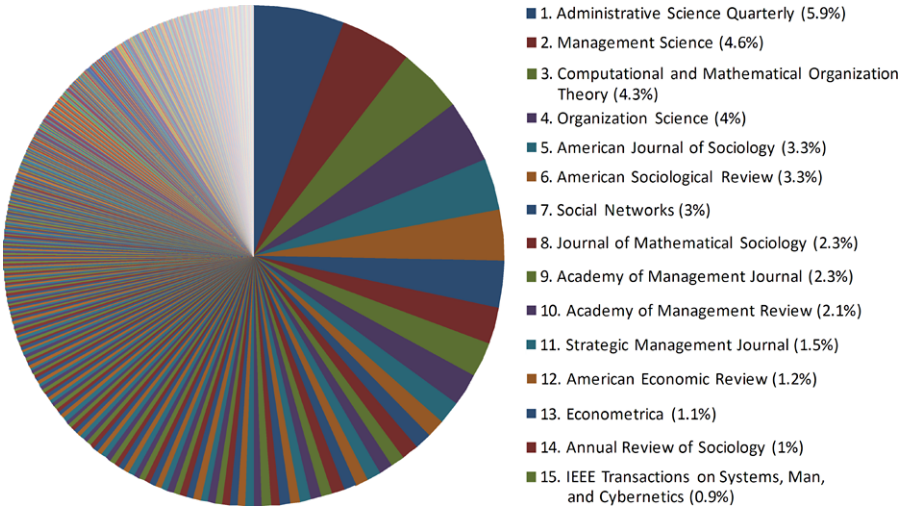

Fig. 3 Most frequently cited journals in CMOT

Review, *Journal of Personality and Social Psychology*, *Complexity*, *CMOT* and *Journal of Economic Dynamics and Control* (all above 1%).[10]

To further determine the interdisciplinary nature of CMOT, we conducted an analysis concerning the disciplinary origins of the journal citations. We used the subject classification of the Institute of Scientific Information (ISI; now Thomson ISI, Philadelphia, PA) for this purpose.[11] Each journal contained in the SSCI/ISI is assigned to at least one subject category. Based on this classification, we were able to attribute 60.3% of the journals to one or more subject categories. If a journal was assigned to several categories, we allocated its share evenly among the different categories. Figure 4 summarizes the results of the analysis and displays the shares of the ISI subject categories.

The results of the analysis deepen our understanding of the interdisciplinary nature of the research published in CMOT. It becomes clear that the cited journals can be assigned to a broad range of different disciplines. The most influential ones are *management*, *sociology*, *business* and *economics* with a total share of 52.4% which reflects the thematic focus of the journal once more. While the analysis of JASSS detects a similar diversity, it reveals a broader coverage for the content that also includes substantial shares of disciplines such as *physics*, *mathematics* or *biology* (Meyer et

[10]The fact that CMOT belongs to the most-cited journals in JASSS, but JASSS ranks only 26th in CMOT's hierarchy, could be interpreted as an indicator that the North American community does not refer to the European community as much as vice versa. However, the age of CMOT compared to JASSS should be considered before drawing this conclusion. CMOT is two years older. During that time, only non-JASSS publications could be cited while JASSS authors could cite CMOT publications from the very beginning. To correct for this effect, we calculated JASSS's rank for the years the journals overlap. This resulted in a minor change, i.e. JASSS ranks in this calculation at position 24.

[11]For a similar approach to assess the extent of a field's interdisciplinarity see Ponzi (2002). The ISI journal categorization has been constructed based on journal subject content and citation information (Klavans and Boyack 2006).

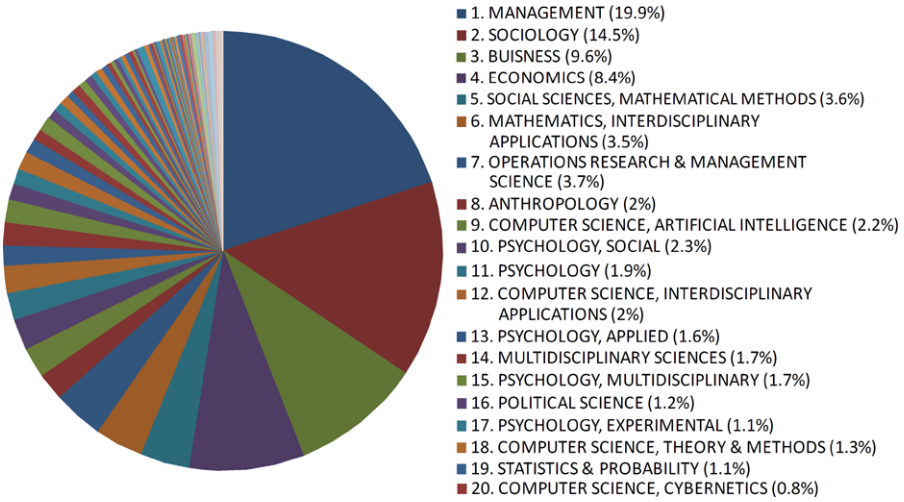

Fig. 4 Disciplines of journal citations based on SSCI

al. 2009). For JASSS, this results in a lower proportion of sources from *management* (3.4%), *sociology* (5.8%), *business* (2.9%) and *economics* (13.1%) with a combined share of about 25.2% which stands in stark contrast to their dominance in CMOT.[12]

5 Co-citation analysis results

We used co-citation analysis to further analyze the intellectual structure of CMOT for the two time periods and to gain a picture of its structural development. We apply the network analysis tool ORA to visualize the resulting co-citation network.[13] The resulting clusters are numbered according to their size in the following figures. Whereas the size of a cluster indicates its importance, the number of relationships between sources is an indicator of the proximity between the sources in a cluster.

Additionally, we analyze the clusters' content by looking for possible thematic points of focus to find out to which extent research foci can be identified. Publication titles, type of journal or publication outlet, disciplinary origin and the method used offer valuable reference points for this purpose. As publications at the center of a cluster can be assumed to have the most in common with other sources, we started with the publications with the most links. Figure 5 gives not only a cluster's number but also a name capturing its underlying essence.[14]

[12] Our χ^2-tests for statistical significance of these differences were clearly supported at $p < 0.001$ for all four categories.

[13] See Carley et al. (2009) and http://www.casos.cs.cmu.edu/projects/ora/index.html.

[14] These are suggested interpretations of the clusters. To reduce the level of subjectivity inevitably involved in such a procedure (Nerur et al. 2008), we discussed our decisions in favor of certain designations not only among the authors but also with a number of subject matter experts. Moreover, we received valuable feedback from several seminar and conference audiences. For transparency, we provide a list of publications

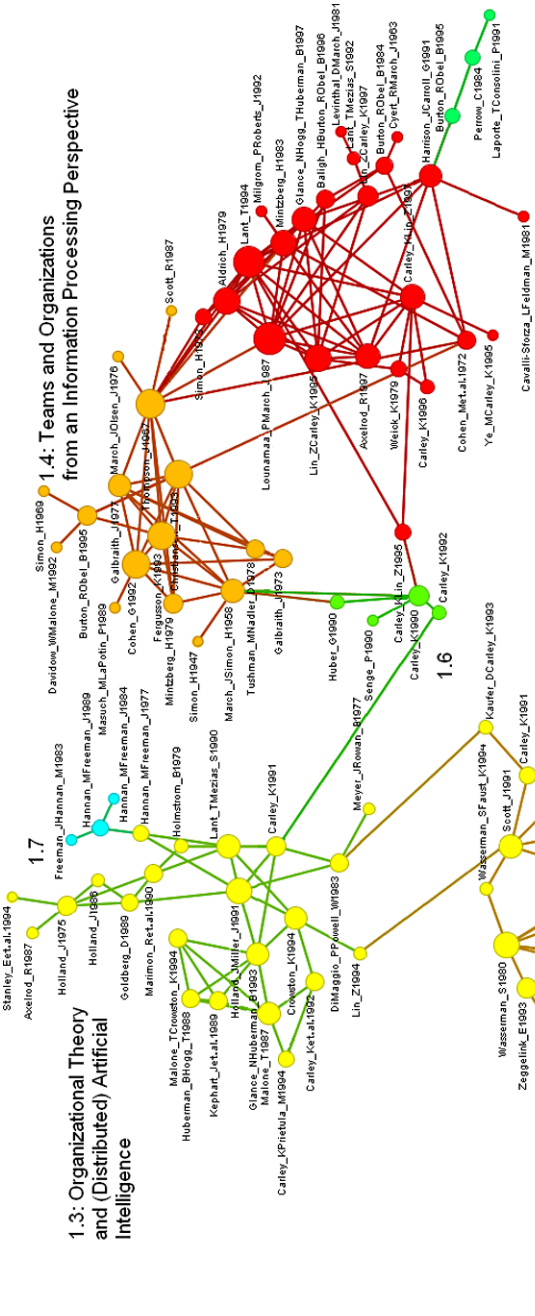

Fig. 5 Co-citation network for Period 1 (1995–2001)

The co-citation network for Period 1 comprises 105 sources. It consists of only one cluster as shown in Fig. 5. As it is both very large and ramified and, thus, difficult to analyze, we used the Newman-Grouping-Algorithm[15] to identify possible groups within the network's clusters and colored the nodes accordingly.

The largest group 1.1 consists of 25 nodes. The most central nodes are Snijders (1991), Weesie and Flap (1990), Banks and Carley (1996) and Wasserman (1980). Thematically, these four publications deal with dynamic social network analysis. Indicative for the sociological and psychological orientation of this group are books such as the ones by Burt (1992) and Heider (1958). Overall, social network theory can be identified as clear thematic focus. The group is connected to group 1.3 and group 1.5.

The second largest group 1.2 includes 23 publications and displays a higher density than group 1.1. Central publications are Lant (1994), Lin and Carley (1995) and Lounamaa and March (1987) that address learning and performance under dynamic conditions. Based on these central publications and many other sources on organizational design and organization theory in this group, we suggest organizational design, learning and adaptation as its central theme.

While group 1.3 is only slightly smaller with 22 nodes, it is much more loosely connected compared to the previous two groups. The papers by Holland and Miller (1991) and Glance and Huberman (1993) form its center. The group does not feature one specific topic, but spans a broad range of organization theory issues including cooperation, coordination and organizational forms. Its distinctive characteristic rests on the research methods used with a clear prevalence of (distributed) artificial intelligence and agent-based modeling.

Group 1.4 is composed of 16 nodes and has a higher density compared to the previous groups. At its center, we find three PhD dissertations addressing teams and information flow: Cohen (1992), Christiansen (1993) and Fergusson (1993). All three of them were completed at the Department of Civil Engineering of Stanford University. Given the overall high share of journals, the dominance of books in this group is remarkable; the group contains only two articles from management journals. Thematically, the cluster focuses on information processing and decision making in organizations, especially in teams.

The nine nodes of group 1.5 are loosely connected to each other. Central publications are Olson (1965) and Festinger et al. (1950). The publications in this group mainly address collective action and groups.

Group 1.6 consists of four nodes. It provides a link between group 1.2 and 1.3 with Carley (1990) serving as the boundary spanner. Organizational learning represents the dominant theme.

included in the networks (see Appendix). To ease tracing back the approach followed in this paper, we structured the list along the different clusters and groups and ordered the publications according to their number of links.

[15]The Newman-Grouping-Algorithm can be used as an indicator for the modularization of communities in networks. The number of edges inside a possible community is related to the number of external edges. This relation decides if a community is supported or if more nodes should be included (Clauset et al. 2004).

The smallest group is 1.7 with only three nodes. All nodes are publications from Michael Hannan and John Freeman. Their topic is organizational ecology and change.

Period 2 exhibits six disjoint clusters encompassing a total of 133 nodes (see Fig. 6). Different specializations have developed at that point and form separate clusters or groups. This differentiation can be seen as an indicator for the field's increasing maturation (Thackray and Merton 1972).

The largest cluster (cluster 1) contains 74 nodes. Due to its size, it is useful to divide this cluster into groups. Following the criteria mentioned before, we distinguished four groups with no less than three strong co-citation relationships and at least one node with more than two edges.

Group 1.1 is structured quite loosely on its periphery but relatively dense at its center. It consists of 39 nodes with the book by Burton and Obel (1995) forming the center. Thomsen (1998), Carroll and Burton (2000), Christiansen (1993) and Jin and Levitt (1996) are located near the core. Organizational design issues and teams represent the main field of interest in this cluster. It seems that group 1.1 is the successor of group 1.4 from Period 1. Exactly one half of the 16 nodes from this group from Period 1 can be found again for group 1.1 in Period 2.

Group 1.2 has 16 publications and its nodes are linked very loosely. It features Burt (1992) as its most central publication. Two thematic center points exist within this group: social networks and organizational ecology. However, the low number of linkages makes it impossible to pinpoint a distinct focus for the group.[16] The shared topic of organizations establishes its connection to group 1.1 and, thus, its affiliation to cluster 1.

With nine nodes and 26 edges, group 1.3 shows a higher linkage than the previous one. Books on management form its center, such as McFarland (1958), Luthans et al. (1988), Mintzberg (1973) and Solow et al. (2002). Management and leadership represent the principal topics addressed by group 1.3.

Group 1.4 is the smallest group of cluster 1. It includes only four nodes with Robins et al. (2002) being the central one. Thematically, the group focuses on the small world phenomenon in networks. The contributions of Milgram (1967) and Watts (1999) on this topic support the label selection for group 1.4.

Cluster 2 encompasses 32 nodes and is divided into two groups. The larger one constitutes group 2.1 and the smaller one group 2.2. The groups are connected by the boundary spanner Keeney and Raiffa (1993).

Group 2.1 consists of 20 nodes and has a very high density. The central nodes are Sterman (1989, 1994), Klein et al. (1993), Fudenberg and Levine (1998), Kanfer and Ackerman (1989) and Joslyn and Hunt (1998). Learning and feedback emerge as the principal topics. This is supported by the fact that many sources are psychology-related and address dynamic decision making.

Group 2.2 with twelve publications is smaller and less dense. Castells (1996), a book on the information age, forms its center. This group mainly addresses societal transition such as the one from an industrial society to the information age or to

[16] When the evidence for assigning a specific designation to a group was insufficient, we refrained from doing so (this was the case for group 1.2). Moreover, we did not give names for 1.6 and 1.7, because they do not fulfill the criteria for a cluster or group.

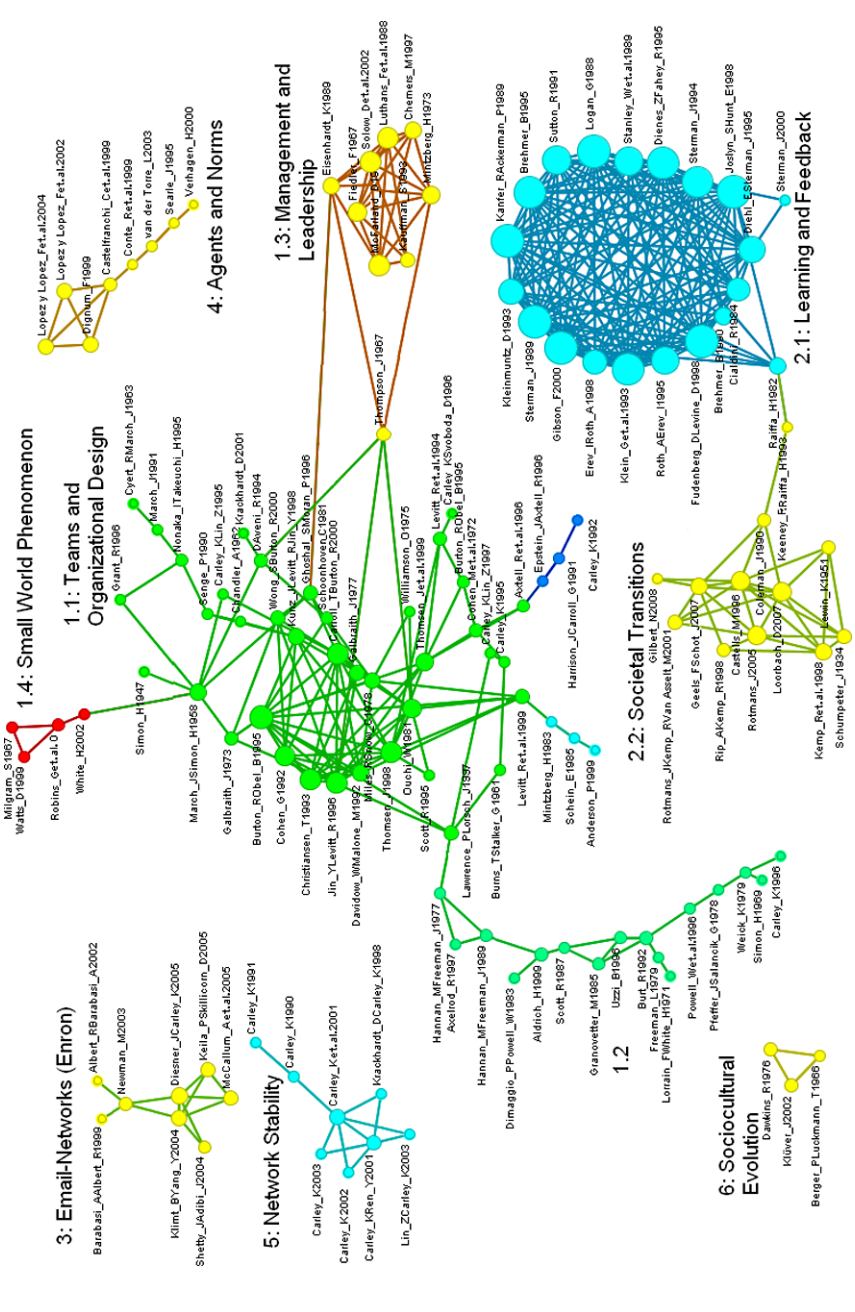

Fig. 6 Co-citation network for Period 2 (2002–2008)

sustainable development. Classics from economics, social psychology or sociology, such as Schumpeter (1934), Lewin (1951) and Coleman (1990), indicate the group's multidisciplinary perspective.

Cluster 3 has eight contributions and relates social network analysis to email exchange and, more particularly, to the email traffic at Enron analyzing a very large dataset. The central nodes are Diesner and Carley (2005) and Klimt and Yang (2004).

Cluster 4 also contains eight publications. Castelfranchi et al. (1999) represents the cluster's central node with agents and norms forming the main theme.

In line with clusters 3 and 4, cluster 5 consists of eight nodes. The stability of networks transpires as the core issue. This evaluation is supported by the fact that the paper of Carley et al. (2001) on this very topic is the most central node. Furthermore, it is remarkable that all sources in this group are either authored or co-authored by Kathleen M. Carley.

Cluster 6 is the smallest one in the second time period. It comprises only three publications, the minimum requirement for being classified a cluster. Thematically, it can be related to sociocultural aspects of evolution.

Looking at the results of the co-citation analysis over the two time periods, a constant clear thematic focus can be noted for CMOT. Most of the identified clusters and groups deal with organizations, groups and network issues. Learning and decision making represents another major topic in the discussion. Therefore, the results of our analysis reflect the journal's thematic focus well. The thematic focus and orientation of the community seem to be quite constant in general. A comparison of the co-citation analyses for the two journals, CMOT and JASSS, confirmed our expectations. They differ in content with JASSS displaying a much broader thematic scope than CMOT. Thematic overlaps only exist in the area of networks, evolution and norms.

From a more general structural perspective on the change over the two analyzed periods, it becomes evident that separable clusters and groups are easier to define in Period 2. While the first network consists of one big cluster with seven groups, the second one shows an increase in both categories featuring six clusters and a total of ten groups. This development is accompanied by a thematic specialization. For example, the social networks group of Period 1 splits into the following three research foci on more specialized network topics in Period 2: the small world phenomenon, network stability and large email networks. Those changes indicate a differentiation of the field through creating more clearly defined lines of research within it. The same structural development has been observed for JASSS. While the journals have this indicator of the field's overall maturation in common, CMOT exhibits a higher number of clearly-defined research foci than JASSS for both periods of time. This suggests that the discussion taking place in CMOT has had clearer core themes from the beginning.

6 Discussion and conclusion

The aim of this paper was to investigate the intellectual structure of computational organization theory as reflected in CMOT and to analyze its development. The results allow for clearly positioning CMOT in the scientific landscape.

First, we showed that a core of codified knowledge (Cole 2004) has already developed. We accomplished this by identifying the most influential publications and analyzing their development over the two time periods. It is remarkable, that a core of specific sources can already be identified as belonging directly to the field (e.g. Carley and Svoboda 1996 or Burton and Obel 1995) rather than to related areas. This core is complemented by classic contributions to organization theory, sociology and network theory. The general finding is similar to the one described for JASSS that has developed a core of codified knowledge as well (Meyer et al. 2009). However, only a very small overlap in content exists regarding the most-cited sources and authors in the two journals (Axelrod 1984, 1997; Epstein and Axtell 1996 and Kauffman 1993).

Second, the description of the field as being highly multidisciplinary (Samuelson and Macal 2006) can be clearly supported. Among the most influential disciplines are management, business, sociology and economics. Our results show that CMOT authors refer to a highly diverse set of journals. Both observations stand out compared to results of studies on management disciplines that are often dominated by just a few disciplines and a small number of journals (Chan and Liano 2009). The results of the co-citation analysis also support the high level of multidisciplinarity as single research topics can be related to a mix of theories from disciplines such as sociology, social psychology and economics. Overall, similar results are reported with respect to JASSS although CMOT focuses more on organizational issues and, therefore, management, business, sociology and economics have a significantly higher share of citations. Furthermore, CMOT has displayed a stronger focus on journal publications from the beginning of Period 1 which stands out in comparison to JASSS. One tentative explanation is the different research and publication traditions of the associated disciplines and communities.

Third, the co-citation analysis yielded foci of research for us to investigate in their development. Organizations, groups and network issues can be identified as central topics in both time periods. As these issues are often related to information processing, learning and adaptation, the observation made by Ashworth and Carley (2007) regarding an intensive use of cognitively realistic and socially embedded agents can be supported for CMOT.[17] With respect to the methods used, we observed a variety of computational methods, such social network analysis, (distributed) artificial intelligence and agent-based modeling. From a structural perspective and similarly to the results for JASSS, one can observe a differentiation over time with more clearly defined lines of research in Period 2. According to the sociology of science, this is typical for the formation of scientific disciplines (Thackray and Merton 1972).

Overall, the results show for CMOT to be thematically focused on organizations, groups and networks, but to be very diverse in terms of disciplines and methods used. The results clearly support the intended orientation of the journal as described in its first editorial (Carley 1995) and formulated in the current call for papers on the

[17] Still, this does not imply that the KISS principle has been abandoned totally in the community. For a discussion of simple vs. realistic models see Burton and Obel (1995) and recently Coen (2009).

journal's website.[18] Examining the entity of the results from our analyses leads us to conclude that CMOT is becoming an established scientific field (Samuelson 2000; Samuelson and Macal 2006).

This study does not only offer empirically grounded information about the development and orientation of the journal; it can also be used to provide interested outsiders with a map of the field's intellectual structure. It gives them a list of core literature and helps to identify possible links to their research by determining the specific research foci. Moreover, such a map can assist existing CMOT researchers in placing their own specialized activities within the broader discipline and in relating it to the work of others. This might also result in connecting previously separate research activities in the future. The boundary spanners identified in our study serve as an indicator for such links to be possible.

As any study, this paper has limitations. First, the paper focused on CMOT and, therefore, is based on only one journal. Due to CMOT's close association with NAACSOS, this can be considered as a reasonable and informative first step that should be extended in the future. Second, our analysis of the co-citation networks focused on identifying the main research foci and analyzing the development of the intellectual structure of CMOT over the two periods. Our data set clearly provides the opportunity to apply a broad range of different techniques and concepts. While we expect that the overall results are stable, additional analyses could reveal further interesting insights. They include but are not limited to investigating the network structure in more detail, analyzing the composition of research foci in terms of methods or disciplines and depicting the evolution of citation network structures (Valverde et al. 2007). Finally, citation studies in general suffer from a certain time lag because it takes some time for publications to appear and to build up a citation record (Hicks 1988). This means that the most current developments in CMOT concerning influential papers and foci of research might not be adequately reflected in our paper. Hence, additional insight can likely be gained from a replication of this study in the future. It would be of particular interest to learn which of the identified research foci continue to exist.

Further research could also address the relationship between JASSS and CMOT more explicitly. An analysis of the change over time in the composition of papers in the two journals would be particularly valuable in providing guidance as to how this field is changing. Moreover, given the fact that both journals are included in the SSCI now, one can expect a positive effect on the impact factor of both journals. In order to enable a better understanding of this effect, it would be interesting to examine what kind of CMOT publications is cited in JASSS and vice versa. Similarly, it would be of interest to investigate the impact of CMOT on other disciplines and to learn whether CMOT is more a sender or receiver of information overall. Such analyses would show which journals and communities are particularly receptive of the research published in CMOT.

[18] http://www.springer.com/cda/content/document/cda_downloaddocument/CALL+FOR+PAPERS+CMOT?SGWID=0-0-45-478999-p35536007 (accessed January 26th 2010).

Appendix

Period 1: 1995–2001

1.1 Social Networks nodes: 25; number of links: 114; density: 0.190	Links
Snijders T (1996) Stochastic actor-oriented models for network change. J Math Sociol 21:149–172	9
Weesie J, Flap H (1990) Social networks through time. Isor, Utrecht	8
Wasserman S (1980) Analyzing social networks as stochastic processes. J Am Stat Assoc 75:280–294	8
Banks DL, Carley KM (1996) Models for network evolution. J Math Sociol 21:173–196	8
Burt R (1992) Structural holes: The social structure of competition. Harvard University Press, Cambridge	7
Carley KM (1990) Group stability: A socio-cognitive approach. In: Lawler E, Markovsky B, Ridgeway C, Walker H (eds) Advances in group processes: Theory and research. Vol. VII. JAI, Greenwich, pp 1–40	6
Doreian P, Stokman F (1997) Evolution of social networks. Routledge, London	6
Scott J (1991) Social network analysis: A handbook. Sage, Newbury Park	5
Freeman LC (1979) Centrality in social networks: Conceptual clarification. Soc Network 1:215–239	5
Holland PW, Leinhardt S (1981) An exponential family of probability distributions for directed graphs. J Am Stat Assoc 76:33–50	5
Heider F (1958) The psychology of interpersonal relations. John Wiley & Sons, New York	5
van Duijn M, Snijders T (1996) P2: A random effects model with covariates for directed graphs. (submitted). (Later published 2004: In: Statistica Neerlandica 58:234–254)	5
Granovetter M (1985) Economic action and social structure: The problem of embeddedness. Am J Sociol 91:481–510	4
Zeggelink EP (1994) Dynamics of structure: An individual oriented approach. Soc Networks 16:295–333	4
Zeggelink EP (1993) Strangers into friends: The evolution of friendship networks using an individual oriented modeling approach. Thesis Publishers, Amsterdam	4
Homans GC (1961) Social behavior: Its elementary forms. Harcourt, Brace & World, New York	3
Carley KM (1991) A theory of group stability. Am Socio Rev 56:331–354	3
Harary F (1969) Graph theory. Addison-Wesley, Reading	3
Leavitt H (1951) Some effects of certain communication patterns on group performance. J Abnorm Soc Psychol 46:38–50	3
Brass DJ, Burkhardt ME (1992) Centrality and power in organizations. In: Nohria N, Eccles R (eds) Networks and organizations: Structure, form, and action. Harvard Business School Press, Boston, pp 191–215	3
Brass DJ (1984) Being in the right place: A structural analysis of individual influence in an organization. Admin Sci Q 29:518–539	3
Coleman J (1990) Foundations of social theory. Harvard University Press, Cambridge	3
Wasserman S, Faust K (1994) Social network analysis: Methods & applications. Cambridge University Press, Cambridge	2
Kaufer D, Carley KM (1993) Communication at a distance: The effect of print on socio-cultural organization and change. Lawrence Erlbaum Associates, Hillsdale	1
Stinchcombe A (1990) Information and organization. University of California Press, Berkeley	1

1.2 Organizational Design, Learning and Adaptation nodes: 23; number of links: 102; density: 0.202	Links
Lant T (1994) Computer simulations of organizations as experiential learning systems: Implications for organization theory. In: Carley KM, Prietula MJ (eds) Computational organization theory. Lawrence Erlbaum Associates, pp 195–215	11
Lin Z, Carley KM (1995) DYCORP: A computational framework for examining organizational performance under dynamic conditions. J Math Sociol 20:193–218	9
Lounamaa P, March J (1987) Adaptive coordination of a learning team. Manag Sci 33:107–123	8
Aldrich HE (1979) Organizations and environments. Prentice-Hall, Englewood Cliffs	7
Mintzberg H (1983) Structure in five: Designing effective organizations. Prentice-Hall, Englewood Cliffs	7
Axelrod R (1997) The complexity of cooperation: Agent-based models of competition and collaboration. Princeton Press, Princeton	7
Harrison J, Carroll G (1991) Keeping the faith: A model of cultural transmission in formal organizations. Admin Sci Q 36:552–582	6
Lin Z, Carley KM (1997) Organizational response: The cost performance tradeoff. Manag Sci 43:217–234	5
Baligh HH, Burton RM, Obel B (1996) Organizational consultant: Creating a useable theory for organizational design. Manag Sci 42:1648–1662	4
Burton RM, Obel B (1984) Designing efficient organizations: Modelling and experimentation. Elsevier, Amsterdam	4
Cohen M, March J, Olsen J (1972) A garbage can model of organizational choice. Admin Sci Q 17:1–23	3
Weick K (1979) The social psychology of organizing. Addison-Wesley, Reading	3
Carley KM, Lin Z (1995) organizational designs suited to high performance under stress. IEEE Trans Syst Man Cybern 25:221–231	2
Simon H (1973) Applying information technology to organization design. Publ Admin Rev 33:268–278	2
Lant T, Mezias S (1992) An organizational learning model of convergence and reorientation. Organ Sci 3:47–71	2
Carley KM (1996) Validating computational models. Working Paper, Pittsburgh	2
Cavalli-Sforza L, Feldman M (1981) Cultural transmission and evolution: A quantitative approach. Princeton University Press, Princeton	1
Levinthal D, March J (1981) A model of adaptive organizational search. J Econ Behav Organ 2:307–333	1
Cyert R, March J (1963) A behavioral theory of the firm. Prentice-Hall, Englewood Cliffs	1
Ye M, Carley KM (1995) Radar-Soar: Towards an artificial organization composed of intelligent agents. J Math Sociol 20:219–246	1
Milgrom P, Roberts J (1992) Economics, organization and management. Prentice-Hall, Englewood Cliffs	1
Glance N, Hogg T, Huberman BA (1997) Training and turnover in the evolution of organizations. Organ Sci 8:84–96	8
Carley KM, Lin Z (1997) A theoretical study of organizational performance under information distortion. Manag Sci 4:976–997	7

1.3 Organizational Theory and (Distributed) Artificial Intelligence nodes: 22; number of links: 77; density: 0.167	Links
Holland JH, Miller JH (1991) Artificial adaptive agents in economic theory. Am Econ Rev 81:365–370	7
Glance N, Huberman B (1993) The outbreak of cooperation. J Math Sociol 17:281–302	7
Lant T, Mezias S (1990) Managing discontinuous change: A simulation study of organizational learning and entrepreneurial strategies. Strat Manag J 11:147–179	6
Malone TW (1987) Modeling coordination in organizations and markets. Manag Sci 33:1317–1332	6
Holland JH (1975) Adaptation in natural and artificial systems. MIT Press	5
Crowston K (1994) Evolving novel organizational forms. In: Carley KM, Prietula MJ (eds) Computational Organization Theory. Lawrence Erlbaum Associates, Hillsdale, pp 19–38	5
Carley KM (1991) Designing organizational structures to cope with communication breakdowns: A simulation model. Ind Environ Crisis Q 5:19–57	4
Goldberg DE (1989) Genetic algorithms in search, optimization and machine learning. Addison Wesley, Reading	4
Marimon R, McGrattan E, Sargent TJ (1990) Money as a medium of exchange in an economy with artificially intelligent agents. J Econ Dynam Contr 14:329–373	4
Malone TW, Crowston K (1994) The interdisciplinary study of coordination. ACM Comput Surv 26:87–119	4
Kephart JO, Hogg T, Huberman BA (1989) Dynamics of computational ecosystems: Implications for DAI. In: Gasser L, Huhns M (eds) Distributed Artificial Intelligence. Morgan Kaufmann, San Francisco, pp 79–96	4
Huberman BA, Hogg T (1988) The behaviour of computational ecologies. In: Huberman BA (ed) The ecology of computation. Elsevier Science Publishers, pp 77–115	4
Carley KM, Kjaer-Hansen J, Newell A, Prietula M (1992) Plural-Soar: A prolegomenon to artificial agents and organizational behavior. In: Masuch M, Warglien M. (eds) Artificial intelligence in organization and management theory. North-Holland, Amsterdam, pp 87–118	3
Hannan MT, Freeman J (1977) The population ecology of organizations. Am J Sociol 82:929–964	2
DiMaggio P, Powell W (1983) The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. Am Socio Rev 48:147–160	2
Holland JH (1986) Escaping brittleness: The possibility of general-purpose learning algorithms applied to rulebased systems. In: Michalski RS, Carbonell JG, Mitchell TM (eds) Machine learning: An artificial intelligence approach, Volume II. Morgan Kaufmann, San Mateo, pp 593–623	2
Holmstrom B (1979) Moral hazard and observability. Bell J Econ 10:4–29	2
Carley KM, Prietula M (1994) Computational organization theory. Lawrence Erlbaum Associates, Hillsdale	2
Lin Z (1994) A theoretical evaluation of measures of organizational design: Interrelationship and performance predictability. In: Carley KM, Prietula MJ (eds) Computational organization theory. Lawrence Erlbaum Associates, Hillsdale, pp 113–159	1
Stanley EA, Ashlock D, Tesfatsion L (1993) Iterated prisoner's dilemma with choice and refusal of partners. In: Langton CG (ed) Artificial Life III. Addison-Wesley, Reading, pp 131–175	1
Axelrod R (1987) The evolution of strategies in the iterated prisoner's dilemma. In: Davies L (ed) Genetic Algorithms and Simulated Annealing. Morgan Kaufmann, London, pp 32–42	1
Meyer J, Rowan B (1977) Institutionalized organizations: Formal structure as myth and ceremony. Am J Sociol 83:340–363	1

1.4 Teams and Organizations from an Information Processing Perspective nodes: 16; number of links: 68; density: 0.283	Links
Cohen GP (1992) The virtual design team: An information processing model of coordination in project design teams. Dissertation, Stanford University, Department of Civil Engineering	8
Christiansen TR (1993) Modeling the efficiency and effectiveness of coordination in engineering design teams. Dissertation, Stanford University, Department of Civil Engineering. Published as Det Norske Veritas Research Report No. 93-2063, Oslo	8
Fergusson KJ (1993) Impact of integration on industrial facility quality. Dissertation, Stanford University, Department of Civil Engineering	8
March JG, Simon HA (1958) Organizations. Wiley, New York	7
Galbraith JR (1977) Organizational design. Addison-Wesley, Reading	7
Thompson JD (1967) Organizations in action. McGraw Hill, New York	7
Mintzberg H (1979) The structuring of organizations. Prentice-Hall, Englewood-Cliffs	5
Burton R, Obel B (1995) Strategic organizational diagnosis and design. Kluwer Academic Publishers, Dordrecht	4
Tushman M, Nadler D (1978) Information processing as an integrating concept in organizational design. Acad Manag Rev 3:613–624	4
Galbraith JR (1973) Designing complex organizations. Addison-Wesley, Boston	4
March JG, Olsen JP (1976) Ambiguity and choice in organizations. Universitetsforlaget, Bergen	1
Scott WR (1987) Organizations: Rational, natural and open systems. Prentice-Hall, Englewood Cliffs	1
Masuch M, LaPonin P (1989) Beyond garbage cans: An AI model of organizational choice. Admin Sci Q 34:38–67	1
Simon HA (1947) Administrative behavior. The Free Press, New York	1
Simon HA (1969) The sciences of the artificial. MIT Press, Cambridge	1
Davidow WH, Malone MS (1992) The virtual corporation. Harper Business, New York	1

1.5 Collective Action and Groups nodes: 9; number of links: 18; density: 0.250	Links
Olson M (1965) The logic of collective action. Harvard University Press, Cambridge	3
Festinger L, Schachter S, Back K (1950) Social pressures in informal groups: A study of a housing project. Harper and Row, New York	3
Pfeffer J (1981) Power in organizations. HarperCollins, New York	2
Rao A, Georgeff M (1991) Modelling rational agents within BDI architecture. In: Proceedings Second International Conference on Principles of Knowledge Representation and Reasoning. pp 473–484	2
Homans G (1950) The human group. Harcourt, New York	2
Krackhardt D, Hanson J (1993) Informal networks: the company behind the chart. Harv Bus Rev 71:104–111	2
Flache A, Macy M (1996) The weakness of strong ties: Collective action failure in highly cohesive groups. J Math Sociol 21:3–28	2
Roethlisberger FJ, Dickson WJ (1939) Management and the worker. Harvard University Press, Cambridge	1
Macy M (1990) Learning theory and the logic of critical mass. Am Socio Rev 55:809–826	1

1.6 (does not fulfill the criteria for a cluster or group) number: 4; number of links: 6; density: 0.500	Links
Carley KM (1990) Group stability: A socio-cognitive approach. In: Lawler E, Markovsky B, Ridgeway C, Walker H (eds) Advances in group processes: Theory and research, Vol. VII. JAI, Greenwich, pp 1–40	3
Huber GP (1990) A theory of the effects of advanced information technologies on organizational design, intelligence, and decision making. Acad Manag Rev 15:47–51	1
Carley KM (1992) Organizational learning and personnel turnover. Organ Sci 3:20–46	1
Senge P (1990) The fifth discipline: The art of practice of the learning organization. Doubleday Press, New York	1

1.7 (does not fulfill the criteria for a cluster or group) nodes: 3; number of links: 4; density: 0.667	Links
Hannan M, Freeman J (1989) Organizational ecology. Harvard University Press, Cambridge	2
Freeman J, Hannan M (1983) Niche width and the dynamics of organizational change. Am J Sociol 88:116–145	1
Hannan M, Freeman J (1984) Structural inertia and organizational change. Am Socio Rev 49:149–164	1

Period 2: 2002–2008

1.1 Teams and Organizational Design nodes: 39; number of links: 177; density: 0.119	Links
Carley KM (1995) Computational and mathematical organization theory: Perspectives and directions. Comput Math Organ Theor 1:39–56	12
Thomsen J (1998) The virtual team alliance (VTA): Modeling the effects of goal incongruency in semiroutine, fast-paced project organizations. Dissertation, Stanford University, Department of Civil Engineering. Published as Det Norske Veritas Research Report No. 98-2024, Oslo	11
Carroll T, Burton RM (2000) Organizations and complexity: Searching for the edge of chaos. Comput Math Organ Theor 6:319–337	11
Christiansen TR (1993) Modeling the efficiency and effectiveness of coordination in engineering design teams. Dissertation, Stanford University, Department of Civil Engineering. Published as Det Norske Veritas Research Report No. 93-2063, Oslo	9
Jin Y, Levitt RE (1996) The virtual design team: A computational model of project organizations. Comput Math Organ Theor 2:171–196	9
Ouchi WG (1981) Theory z: How American business can meet the Japanese challenge. Avon, New York	8
Thomsen J, Levitt RE, Kunz JC, Nass CI, Fridsma DB (1999) A trajectory for validating computational emulation models of organizations. Comput Math Organ Theor 5:385–401	8
Cohen GP (1992) The virtual design team: An object-oriented model of information sharing in project teams. Dissertation, Stanford University, Department of Civil Engineering	8
Davidow WH, Malone MS (1992) The virtual corporation. Harper Business, New York	7
Kunz JC, Levitt RE, Jin Y (1999) The virtual design team: A computational simulation model of project organizations. Comm ACM 41:84–92	7
March JG, Simon HA (1958) Organizations. Wiley, New York	6

1.1 Teams and Organizational Design (*Continued*)	Links
Miles RE, Snow CC (1978) Organizational strategy, structure and process. McGraw Hill, New York	6
Levitt RE, Thomsen J, Christiansen TR, Kunz JC, Jin Y, Nass CI (1999) Simulating project work processes and organizations: Toward a micro-contingency theory of organizational design. Manag Sci 45:1479–1495	5
Galbraith, JR (1977) Organization design. Addison-Wesley, Reading	5
Wong SS, Burton RM (2000) Virtual teams: What are their characteristics, and impact on team performance? Comput Math Organ Theor 6:339–360	5
Lawrence P, Lorsch J (1967) Organization and environment: Managing differentiation and integration. Harvard University Press, Boston	4
Ghoshal S, Moran P (1996) Bad for practice: A critique of the transaction cost theory. Acad Manag Rev 21:13–47	4
Cohen M, March J, Olsen J (1972) A garbage can model of organizational choice. Admin Sci Q 17:1–23	4
Levitt RE, Cohen GP, Kunz JC, Nass CI, Christiansen T, Jin Y (1994) The virtual design team: Simulating how organization structure and information processing tools affect team performance. In: Carley KM, Prietula MJ (eds) Computational organization theory. Lawrence Erlbaum, Hillsdale, pp 1–8	4
Galbraith JR (1973) Designing complex organizations. Addison-Wesley, Reading	4
D'Aveni RA (1994) Hypercompetition: Managing the dynamics of strategic maneuvering. Free Press, New York	3
Carley KM (1995) Computational and mathematical organization theory: Perspectives and directions. Comput Math Organ Theor 1:39–56	3
Burton RM, Obel B (1995) The validity of computational models in organization science: From model realism to purpose of the model. Comput Math Organ Theor 1:57–71	3
Nonaka I, Takeuchi H (1995) The knowledge creating company. Oxford University Press, New York	3
Senge P (1990) The fifth discipline: The art of practice of the learning organization. Doubleday Press, New York	3
Schoonhoven CB (1981) Problems with contingency theory: Testing assumptions hidden within the language of contingency 'theory'. Admin Sci Q 26:349–377	3
Axtell R, Axelrod R, Epstein JJ, Cohen MD (1996) Aligning simulation models: A case study and results. Comput Math Organ Theor 1:123–142	2
Carley KM, Lin Z (1997) A theoretical study of organizational performance under information distortion. Manag Sci 43:977–997	2
Burns T, Stalker GM (1961) The management of innovation. Tavistock, London	2
Scott WR (1995) Institutions and organizations. Sage, Thousand Oaks	2
Williamson OE (1975) Markets and hierarchies, analysis and antitrust implications: A study of the economics of internal organization. Free Press, New York	2
Carley KM, Lin Z (1995) Organizational designs suited to high performance under stress. IEEE Trans Syst Man Cybern 25:221–231	2
Grant RM (1996) Toward a knowledge-based theory of the firm. Strat Manag J 17:109–122	2
March JG (1991) Exploration and exploitation in organizational learning. Organ Sci 2:71–87	2
Chandler AD (1962) Strategy and structure: Chapters in the history of industrial enterprise. Harvard University Press, Cambridge	2

1.1 Teams and Organizational Design (*Continued*)	Links
Carley KM, Svoboda DM (1996) Modeling organizational adaptation as simulated annealing process. Socio Meth Res 25:138–168	1
Simon HA (1947) Administrative behavior. The Free Press, New York	1
Cyert RM, March JG (1963) A behavioral theory of the firm. Prentice-Hall, Englewood Cliffs	1
Krackhardt D (2001) Viscosity models and the diffusion of controversial innovations. In: Lomi A, Larsen R (eds) Dynamics of organizations. MIT Press, pp 243–268	1

1.2 (not sufficient indicators for clear designation) nodes: 16; number of links: 36; density: 0.150	Links
Burt R (1992) Structural holes: The social structure of competition. Harvard University Press, Cambridge	4
Weick K (1979) The social psychology of organizing. Addison-Wesley, Reading	3
Uzzi B (1996) The sources and consequences of embeddedness for the economic performance of organizations: The network effect. Am Socio Rev 61:674–698	3
Granovetter M (1985) Economic action and social structure: The problem of embeddedness. Am J Sociol 91:481–510	3
Scott WR (1987) Organizations: Rational, natural and open systems. Prentice-Hall, Englewood Cliffs	3
Aldrich H (1999) Organizations evolving. Sage, Newbury Park	3
Hannan MT, Freeman JH (1989) Organizational ecology. Harvard University Press, Cambridge	3
Hannan MT, Freeman JH (1977) The population ecology of organizations. Am J Sociol 82:929–964	2
Pfeffer J, Salancik G (1978) The external control of organizations: A resource dependence perspective. Harper and Row, New York	2
Powell WW, Koput KW, Smith-Doerr L (1996) Interorganizational collaboration and the locus of innovation. Admin Sci Q 41:116–145	2
Freeman LC (1979) Centrality in social networks: Conceptual clarifications. Soc Netw 1:215–239	2
Axelrod R (1997) Advancing the art of simulation in the social sciences. Lect Notes Econ Math Syst 456:21–40	2
Carley KM (1996) Validating computational models. Working Paper, Pittsburgh	1
Simon HA (1969) The sciences of the artificial. MIT Press, Cambridge	1
Lorrain F, White HC (1971) Structural equivalence of individuals in social networks. J Math Sociol 1:49–80	1
DiMaggio PJ, Powell WW (1983) The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. Am Socio Rev 48:147–160	1

1.3 Management and Leadership nodes: 9; number of links: 52; density: 0.722	Links
McFarland DE (1958) Management principles and practices. MacMillan, New York	7
Luthans F, Hodgetts RM, Rosenkrantz SA (1988) Real managers. Ballinger Publishing Company, Cambridge	7
Mintzberg H (1973) The nature of managerial work. Harper and Row, New York	7

1.3 Management and Leadership (*Continued*)	Links
Solow D, Vairaktarakis G, Piderit SK, Tsai M (2002) Managerial insights into the effects of interdependences on replacing members of a team. Manag Sci 48:1060–1073	7
Eisenhardt KM (1989) Agency theory: An assessment and review. Acad Manag Rev 14:57–74	6
Chemers MM (1997) An integrative theory of leadership. Lawrence Erlbaum, Mahwah	6
Fiedler FE (1967) A theory of leadership effectiveness. McGraw Hill, London	6
Kauffman SA (1993) The origins of order: Self-organization and selection in evolution. Oxford University Press, Oxford	4
Thompson JD (1967) Organizations in action. McGraw Hill, New York	2

1.4 Small World Phenomenon nodes: 4; number of links: 8; density: 0.667	Links
Robins GL, Pattison PE, Woolcock J (2005) Small and other worlds: Global network structures from local processes. Am J Sociol 96:626–654	3
Milgram S (1967) The small world problem. Psychol Today 2:60–67	2
Watts DJ (1999) Small worlds: The dynamics of networks between order and randomness. Princeton University Press, Princeton	2
White H (2002) Markets from networks: Socioeconomic models of production. Princeton University Press, Princeton	1

2.1 Learning and Feedback nodes: 20; number of links: 263; density: 0.692	Links
Sterman J (1989) Misperceptions of feedback in dynamic decision making. Organ Behav Hum Decis Process 43:301–335	17
Sterman J (1994) Learning in and about complex systems. Syst Dynam Rev 10:291–330	17
Klein GA, Orasanu J, Calderwood R, Zsambok CE (1993) Decision making in action: Models and methods. Ablex, Norwood	17
Fudenberg D, Levine D (1998) The theory of learning in games. MIT Press	17
Kanfer R, Ackerman PL (1989) Motivation and cognitive abilities: An integrative aptitude-treatment approach to skill acquisition. J Appl Psychol 74:657–690	17
Joslyn S, Hunt E (1998) Evaluating individual differences in response to time-pressure situations. J Exp Psychol Appl 4:16–43	17
Dienes Z, Fahey R (1995) Role of specific instances in controlling a dynamic system. J Exp Psychol Learn Mem Cognit 21:848–862	16
Roth AE, Erev I (1995) Learning in extensive-form games: Experimental data and simple dynamic models in the intermediate term. Game Econ Behav 8:164–212	15
Kleinmuntz DN (1993) Information processing and misperceptions of the implications of feedback in dynamic decision making. Syst Dynam Rev 9:223–237	15
Sutton RI (1991) Maintaining norms about expressed emotions: The case of bill collectors. Admin Sci Q 36:245–268	15
Stanley WB, Mathews RC, Buss RR, Kotler-Cope S (1989) Insight without awareness: One the interaction of verbalization, instruction and practice in a simulated process control task. QJ Exp Psychol B 41A:553–577	15

2.1 Learning and Feedback (*Continued*)	Links
Erev I, Roth AE (1998) Predicting how people play games: Reinforcement learning in experimental games with unique, mixed strategy equilibria. Am Econ Rev 88:848–881	14
Diehl E, Sterman JD (1995) Effects of feedback complexity on dynamic decision making. Organ Behav Hum Decis Process 2:198–215	14
Cialdini R (1984) Influence: The psychology of persuasion. Collins, New York	13
Gibson FP (2000) Feedback delays: How can decision makers learn not to buy a new car every time the garage is empty? Organ Behav Hum Decis Process 83:141–166	12
Logan GD (1988) Toward an instance theory of automatization. Psychol Rev 95:492–527	12
Raiffa H (1982) The art and science of negotiation. Harvard University Press, Cambridge	6
Brehmer B (1990) Strategies in real-time, dynamic decision making. In: Hogarth R (ed) Insights from decision making. University of Chicago Press, Chicago	6
Brehmer B (1995) Feedback delays in complex dynamic decision tasks. In: Frensch P, Funke J (eds) Complex problem solving: The European Perspective. Lawrence Erlbaum, Hillsdale	6
Sterman JD (2000) Business dynamics: Systems thinking and modeling for a complex world. McGraw Hill, New York	2

2.2 Societal Transitions nodes: 12; number of links: 59; density: 0.447	Links
Castells M (1996) The information age: Economy, society, and culture, Vol. 1: The rise of the network society. Blackwell, Oxford	9
Rotmans J (2005) Societal innovation: Between dream and reality lies complexity. Erasmus University Rotterdam, Rotterdam	7
Geels FW, Schot J (2007) Typology of socio-technical transition pathways. Res Pol 36:399–417	7
Loorbach D (2007) Transition management: New mode of governance for sustainable development. International Books, Utrecht	7
Kemp R, Schot J, Hoogma R (1998) Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. Tech Anal Strat Manag 10:175–195	6
Schumpeter JA (1934) Theory of economic development. Harvard University Press, Cambridge	5
Rotmans J, Kemp R, van Asselt M (2001) More evolution than revolution: Transition management in public policy. Foresight 3:15–31	4
Lewin K (1951) Field theory in social science. Harper and Row, New York	4
Coleman J (1990) Foundations of social theory. Belknap Press, Cambridge	4
Rip A, Kemp R (1998) Technological change. In: Rayner S, Malone E (eds) Human choices and climate change. Battelle, Columbus	3
Gilbert N (2008) Agent-based models. Sage, London	2
Keeney R, Raiffa H (1993) Decisions with multiple objectives: Preferences and value tradeoffs. Cambridge University Press, Cambridge	1

3 Email-networks (Enron) nodes: 8; number of links: 24; density: 0.429	Links
Klimt B, Yang Y (2004) The Enron corpus: A new dataset for email classification research. European Conference on Machine Learning, Pisa, Italy	5
Diesner J, Carley KM (2005) Exploration of communication networks from the Enron email corpus. In: Proceedings of Workshop on Link Analysis, Counterterrorism and Security, SIAM International Conference on Data Mining 2005. Newport Beach, pp 3–14	5

3 Email-networks (Enron) (*Continued*)	Links
Newman ME (2003) The structure and function of complex networks. SIAM Rev 45:167–256	4
McCallum A, Corrada-Emmanuel A, Wang X (2005) The author-recipient-topic model for topic and role discovery in social networks, with application to Enron and academic email. In: Proceedings of Workshop on Link Analysis, Counterterrorism and Security, SIAM International Conference on Data Mining 2005. Newport Beach, pp 33–44	3
Keila PS, Skillicorn DB (2005) Structure in the Enron email dataset. In: Proceedings of Workshop on Link Analysis, Counterterrorism and Security, SIAM International Conference on Data Mining 2005. Newport Beach, pp 55–64	3
Shetty J, Adibi J (2004) The Enron dataset database schema and brief statistical report. http://www.isi.edu/~adibi/Enron/Enron Dataset Report.pdf	2
Barabasi AL, Albert R (1999) Emergence of scaling in random networks. Sci 286:509–512	1
Albert R, Barabasi AL (2001) Statistical mechanics of complex networks. Rev Mod Phys 74:47–97	1

4 Agents and Norms nodes: 8; number of links: 20; density: 0.357	Links
Castelfranchi C, Dignum F, Jonker C, Treur J (1999) Deliberate normative agents: Principles and architecture. In: Proceedings of ATAL'99. Springer, Berlin	4
López Y, López F, Luck M, d'Inverno M (2004) Normative agent reasoning in dynamic societies. Paper presented at the Third International Joint Conference on Autonomous Agents & Multi Agent Systems (AAMAS), New York, pp 19–23	3
Dignum F (1999) Autonomous agents with norms. Artif Intell Law 7:69–79	3
López Y, López F, Luck M, d'Inverno M (2002) Constraining autonomy through norms. In: Proceedings of the first international joint conference on Autonomous agents and multi agent systems: Part 2. Bologna, pp 15–19	3
Conte R, Falcone R, Sartor G (1999) Introduction: Agents and norms: How to fill the gap? Artif Intell Law 7:1–15	2
van der Torre L (2003) Contextual deontic logic: Normative agents, violations and independence. Ann Math Artif Intell 37:33–63	2
Searle J (1995) The construction of social reality. Free Press, New York	2
Verhagen H (2000) Norm autonomous agents. Thesis, Stockholm University	1

5 Network Stability nodes: 8; number of links: 22; density: 0.393	Links
Carley KM, Lee JS, Krackhardt D (2001) Destabilizing networks. Connections 24:31–34	6
Carley KM, Ren Y (2001) Tradeoffs between performance and adaptability for C3I architectures. In: Proceedings of the 2001 Command and Control Research and Technology Symposium. Annapolis	5
Carley KM (2003) Dynamic network analysis. In: Breiger R, Carley KM, Pattison P (eds) Dynamic social network modeling and analysis: Workshop summary and papers, committee on human factors, national research council. Washington, pp 133–145	2
Krackhardt D, Carley KM (1998) A PCANS model of structure in organizations. In: Proceedings of the 1998 International Symposium on Command and Control Research and Technology. Monterray	2

5 Network Stability (*Continued*)	Links
Lin Z, Carley KM (2003) Designing stress resistant organizations: Computational theorizing and crisis applications. Kluwer Academic Publishers, Boston	2
Carley KM (2002) Smart agents and organizations of the future. In: Lievrouw LA, Livingstone SM (eds) Handbook of New Media. Sage, Thousand Oaks, pp 206–220	2
Carley KM (1990) Group stability: A socio-cognitive approach. In: Lawler E, Markovsky B, Ridgeway C, Walker H (eds) Advances in group processes: Theory and research, Vol. VII. JAI Press, Greenwich, pp 1–44	2
Carley KM (1991) A theory of group stability. Am Socio Rev 56:331–354	1

6 Sociocultural Evolution nodes: 3; number of links: 6; density: 1.0	Links
Dawkins R (1976) The selfish gene. Oxford University Press, New York	2
Klüver J (2002) An essay concerning sociocultural evolution: Theoretical principles and mathematical models. Kluwer Academic Publishers, Dordrecht	2
Berger PL, Luckmann T (1966) Social construction of reality. Doubleday, New York	2

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Ahlgren P, Jarneving B, Rousseau R (2003) Requirements for a cocitation similarity measure, with special reference to pearson's correlation coefficient. J Am Soc Inf Sci Technol 54:550–560

Ashworth MJ, Carley KM (2007) Can tools help unify organization theory: perspectives on the state of computational modelling. Comput Math Organ Theory 13:89–111

Bricker R (1988) Knowledge preservation in accounting: a citational study. Abacus 24:120–131

Burton RM, Obel B (1995) The validity of computational models in organization science: from model realism to purpose of the model. Comput Math Organ Theory 1:57–71

Carley KM (1995) Computational and mathematical organization theory: perspective and directions. Comput Math Organ Theory 1:39–56

Carley KM, Wallace WA (1995) Editorial. Comput Math Organ Theory 1:5–7

Carley KM, Reminga J, Storrick J, DeReno M (2009) ORA user's guide 2009, Carnegie Mellon University, School of Computer Science, Institute for Software Research, Technical Report CMU-ISR-09-115

Chan KC, Liano K (2009) Threshold citation analysis of influential articles, journals, institutions and researchers in accounting. Account Finance 49:49–74

Charvet FF, Cooper MC, Gardner JT (2008) The intellectual structure of supply chain management: a bibliometric approach. J Bus Logist 29:47–73

Chen C, Paul RJ (2001) Visualizing a knowledge domain's intellectual structure. Computer 34:65–71

Clauset A, ME Newman, Moore C (2004) Finding community structure in very large networks. Phys Rev E 70

Coen C (2009) Simple but not simpler. Comput Math Organ Theory 15:1–4

Cole S (1983) The hierarchy of the sciences? Am J Sociol 89:111–139

Cole S (2004) Merton's contribution to the sociology of science. Soc Stud Sci 34:829–844

Crane D (1972) Invisible colleges: diffusion of knowledge in scientific communities. University of Chicago Press, Chicago

Cronin B (1984) The citation process: the role and significance of citations in scientific communication. Taylor Graham, London

Franklin JJ (1988) Testing and using quantitative methods in science policy contexts: a response to Hicks. Sci Soc Stud 18:365–375

Gilbert N (1997) A simulation of the structure of academic science. Socio Res Online 2

Gmür M (2003) Co-citation analysis and the search for invisible colleges: a methodological evaluation. Scientometrics 57:27–57

Hicks D (1987) Limitations of co-citation analysis as a tool for science policy. Soc Stud Sci 17:295–316
Hicks D (1988) Limitations and more limitations of co-citation analysis/bibliometric modelling: a reply to Franklin. Soc Stud Sci 18:375–384
Klavans R, Boyack KW (2006) Identifying a better measure of relatedness for mapping science. J Am Soc Inf Sci Technol 57:251–263
Kuhn TS (1970) The structure of scientific revolutions. University of Chicago Press, Chicago
Lunin LF, White HD (1990) Author cocitation analysis, introduction. J Am Soc Inf Sci Technol 41:429–432
McCain KW (1986) Cocited author mapping as a valid representation of intellectual structure. J Am Soc Inf Sci 37:111–122
Merton RK (1979) The sociology of science: theoretical and empirical investigations. University of Chicago Press, Chicago
Merton RK, Zuckerman H (1972) Age, aging, and age structure in science. Russell Sage Foundation, New York
Meyer M, Lorscheid I, Troitzsch KG (2009) The development of social simulation as reflected in the first ten years of JASSS: a citation and co-citation analysis. J Artif Soc Soc Simulat 12
Moed HF (2002) The impact-factors debate: the ISI's uses and limits. Nature 415:731–732
Mullins NC, Hargens LL, Hecht PK, Kick EL (1977) The group structure of cocitation clusters: a comparative study. Am Sociol Rev 42:552–562
Nerur SP, Natarajan V Rasheed AA (2008) The intellectual structure of the strategic management field: an author co-citation analysis. Strateg Manag J 29:319–336
Osareh F (1996a) Bibliometrics citation analysis and co-citation analysis I: a review of literature. Libri 46:149–158
Osareh F (1996b) Bibliometrics citation analysis and co-citation analysis II: a review of literature. Libri 46:217–225
Ponzi LJ (2002) The intellectual structure and interdisciplinary breadth of knowledge management: a bibliometric study of its early stage of development. Scientometrics 55:259–272
Prus RC (1996) Symbolic interaction and ethnographic research: intersubjectivity and the study of human lived experience. State University of New York Press, New York
Ramos-Rodriguez AR, Ruiz-Navarro J (2004) Changes in the intellectual structure of strategic management research: a bibliometric study of the Strategic Management Journal. Strateg Manag J 25:981–1004
Samuelson D (2000) Designing organizations. OR/MS Today, 1–4
Samuelson D, Macal C (2006) Agent-based simulation comes of age. OR/MS Today 33:34–38
Small HG (1978) Cited documents as concept symbols. Soc Stud Sci 8:327–340
Small HG (1980) Co-citation context analysis and the structure of paradigms. J Doc 36:183–196
Tempest D (2009) Breaking boundaries: patterns in interdisciplinary citation. http://www.info.scopus.com/researchtrends/archive/RT11/bib_mes_11.html, download: February 5th 2010
Thackray A, Merton RK (1972) On discipline building: the paradoxes of George Sarton. Isis 63:473–495
Valverde S, Solé RV, Bedau MA, Packard N (2007) Topology and evolution of technology innovation networks. Phys Rev E 76:56118

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