Annex 2b **Szczecin, 25 April 2017**

Summary of scientific achievements

Personal data

Jarosław Jankowski, PhD

Diplomas and degrees

2013 - University of Szczecin, postgraduate studies “Research project management and commercialization of research results“.

2003 - Technical University of Szczecin, Faculty of Computer Science and Information Technology, PhD in computer science, speciality: decision support systems, Thesis: *Multi-criteria optimization of advertising campaigns on the Internet.*

1997 - Technical University of Szczecin, Faculty of Computer Science and Information Technology, MSc in computer science, speciality: decision support systems.

Information about employment

2009 - now, West Pomeranian University of Technology in Szczecin, Faculty of Computer Science and Information Technology, Department of Information Systems Engineering, position: assistant professor, since 2013 the head of the Information Systems Department transformed in 2016 into the Department of Web Analytics and Data Processing, since 2016 the head of the Department of Information Systems Engineering.

2004 - 2009, Technical University of Szczecin, Faculty of Computer Science and Information Technology, Department of Information Systems, position: assistant professor.

1997 – 2004, Technical University of Szczecin, Faculty of Computer Science and Information Technology, Department of Information Systems, position: assistant.

Online profiles

Personal website: jjankowski.zut.edu.pl

ResearchGate: https://www.researchgate.net/profile/Jaroslaw_Jankowski

GoogleScholar: https://scholar.google.pl/citations?user=xZJ38c4AAAAJ

DBLP: http://dblp.uni-trier.de/pers/hd/j/Jankowski:Jaroslaw

Scientific achievement

To demonstrate scientific achievement, I indicated a series of thirteen thematically-related publications with the title "**Modeling of internal space of online social platforms**". The set includes eight articles published in scientific journals from Journal Citation Reports and five articles published by peer-reviewed conference publishers such as Springer and IEEE indexed in the Web of Science.

A1 **Jankowski, J.**, Bródka, P., Kazienko, P., Szymanski, B., Michalski, R., Kajdanowicz, T.: **Balancing Speed and Coverage by Sequential Seeding in Complex Networks**, Scientific Reports, Nature Publishing Group**,** 2017, VOL DOI: 10.1038/s41598-017-00937-8
***IF = 5.228**, 40 points, contribution 50%*
Contribution: leading contributor in the development of algorithms for sequential initiation of information propagation processes in complex networks, experiment planning, development of simulation environment, conducting of simulations, implementation of reference algorithms and comparison of their effectiveness, significant participation in data analysis and manuscript preparation.

A2 **Jankowski, J.**: **Dynamic Rankings for Seed Selection in Complex Networks**, Entropy 2017, 19(4), 170; doi:10.3390/e19040170
***IF = 1.743**, 30 points*, *contribution 100%*

A3 **Jankowski, J.**, Michalski, R.: **Increasing Coverage of Information Spreading in Social Networks with Supporting Seeding**, The Second International Conference on Data Mining and Big Data , IEEE Conference #41362, 07.2017, Springer, LNCS, 2017
Indexed in WebOfScience, 15 points, contribution 90%
Contribution: research concept, development of supporting seeding algorithms, experiment planning, development of a simulation environment, conducting of simulations, data analysis and manuscript preparation.

A4 **Jankowski, J.**: **Mixture Seeding for Sustainable Information Spreading in Complex Networks**, Asian Conference on Intelligent Information and Database Systems, Springer, LNCS, vol. 10191, pp. 191-201, 2017
Indexed in WebOfScience, 15 points, *contribution 100%*

A5 **Jankowski, J.**, Michalski, R., Kazienko, P. : **Compensatory Seeding in Networks with Varying Availability of Nodes**, Proceedings of the 2013 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining, ACM, pp. 1242-1249, 2013
Indexed in WebOfScience, 15 points, contribution 80%
Contribution: the concept of compensatory seeding, planning of experiments, development and implementation of algorithms, leading in data analysis and manuscript development.

A6 Różewski, P., **Jankowski, J.**, Bródka, P., Michalski, R.: **Knowledge workers' collaborative learning behavior modeling in an organizational social network**, Computers in Human Behavior, vol. 51, pp. 1248-1260, 2015
***IF = 2.88**, 40 points, contribution 25%*
Contribution: participation in the development of conceptual framework and assumptions of theoretical models, significant participation in the implementation of models in the

simulation environment, significant participation in the implementation of simulation research, participation in data analysis and manuscript development.

A7 Różewski, P., **Jankowski, J.**: **Model of Multilayer Knowledge Diffusion for Competence Development in an Organization**, Mathematical Problems in Engineering. Article ID 529256, 2015
***IF = 0.644**, 25 points, contribution 35%*
Contribution: participation in the development of theoretical models involving multilayer networks, participation in the development of the plan of research and determination of the experimental space, significant participation in the implementation of models in the agent based environment and conducting simulation research, participation in data analysis and manuscript elaboration.

A8 **Jankowski, J.**, Michalski, R., Bródka, P., Kazienko, P., Utz, S.: **Knowledge acquisition from social platforms based on network distributions fitting**, Computers in Human Behavior, vol. 51, pp. 685-693, 2015
***IF = 2.88**, 40 points, contribution 40%*
Contribution: a network sampling concept focused on matching sample characteristics to network parameter distributions, implementation of survey module, significant contribution to the development of sampling algorithms, important contribution to the data analysis and manuscript development.

A9 **Jankowski, J.**, Michalski, R., & Kazienko, P.: **The Multidimensional Study of Viral Campaigns as Branching Processes**, International Conference on Social Informatics, LNCS, vol. 7710, Springer Berlin Heidelberg, pp. 462-474, 2012
Indexed in WebOfScience, 15 points, contribution 80%
Contribution: the concept of using generations based approach in analyzing and predicting the information dissemination processes, analysis of data from real campaigns, development and implementation of predictive algorithm, significant participation in simulations, data analysis and manuscript development.

A10 **Jankowski, J.**, Bródka, P., Hamari, J.: **A Picture is Worth a Thousand Words: an Empirical Study on the Influence of Content Visibility on Diffusion Processes within a Virtual World**, Behaviour & Information Technology, vol. 35(11), pp. 926-945, 2016
***IF = 1.211**, 25 points, contribution 50%*
Contribution: the concept of experimental research, the implementation of digital product transmission mechanisms and the implementation of experiments in the real environment, significant participation in statistical analyzes and the development of manuscript.

A11 Utz, S., **Jankowski, J.**: **Making "friends" in a virtual world: The role of preferential attachment, homophily, and status**, Social Science Computer Review, vol. 34(5), pp. 546-566, 2016
***IF = 1.364**, 30 points, contribution 25%*
Contribution: the initial concept of research, implementation of measurement systems in the real environment, data processing and preliminary analysis, development of the manuscript part related to the description of experiments and participation in the final development of the entire manuscript.

A12 **Jankowski, J.**, Kolomvatsos, K., Kazienko, P., Wątróbski, J. : **Fuzzy Modeling of User Behaviors and Virtual Goods Purchases in Social Networking Platforms**, Journal of Universal Computer Science, vol. 22(3), pp. 416-437, 2016

***IF = 0.546**, 15 points, contribution 70%*
Contribution: research concept, data acquisition from real system and data preprocessing, leading participation in fuzzy inference system design, analysis and interpretation of results, manuscript preparation.

A13 Jankowski, J.: Analysis of Multiplayer Platform Users Activity Based on the Virtual and Real Time Dimension, International Conference on Social Informatics (SocInfo '2011), Springer, LNCS, vol. 6984, pp. 312-315, 2011
Indexed in WebOfScience, 15 points, *contribution 100%*

The following table summarizes bibliometric indicators of the series of thematically-related publications:

Table 1. Bibliometric indicators of the series of thematically-related publications

Indicator name	**Value**
Summarized Impact Factor	16.5
Summarized ministry points	320
Summarized ministry points by authors share	184.25

Scientific activity

Since the beginning of scientific research at the Department of Computers Science of Technical University of Szczecin in 1997 (re-named into the West Pomeranian University of Technology in 2009), my interests have been connected with decision support methods, human-computer interaction and Internet systems.

The research concerning Internet systems ranged from their earlier applications at the turn of the century, through to Web 2.0, and to the development of social platforms. The research is part of the computer science fields included in the Association for Computer Machinery's ('the ACM's) classification as human-centered computing among the thirteen mainstream areas of computer science. More narrowly the classification includes the areas of human-computer interaction, social media and social networks. My primary aims for much of the research were to link the modeling of social systems and information diffusion processes, to better understand the optimization of online systems, and to apply eye tracking and perceptual analysis knowledge to applications of multi-criteria decision support methods in systems design.

My Initial research was published in national publications. With the tendency of internationalization of research, there was a reorientation towards to international publications and conferences.

The research has been focused on new methods, algorithms and techniques for the analysis of phenomena inside online social platforms. Examples of such include investigating propagation of information and digital content, user-oriented modeling, adaptive interactive components as well as better analysis of social networking platforms. The formal conceptual framework or methodology of the research, includes agent based simulation models, decision support methods, fuzzy modeling, inference systems and statistical inference. The research efforts have also resulted in practical application with a number of the studies resulting in solutions which have been implemented in cooperation with firms in the online industry through joint projects and research internships.

Discussion of objectives and results achieved

Online social systems integrate social, technical and economic elements and play an increasingly important role in the different spheres of the economy and society [4]. Such is confirmed by the dynamic development of social platforms and the numbers of users, in the hundreds of millions, for the larger services such as Facebook or Twitter. The proliferation of new media systems is accompanied by rapid data growth, in both relational and object-oriented databases as well as in relation to text and multimedia linked to various forms of user activity, use of games, multimedia content, transactional systems, virtual products and digital services [6]. For example, users on Facebook upload over 250 million images each day [7]. Complex data structures arise as a result in the form of interactions and relationships represented by social networks. Based on user activity within the social platforms, it is possible to deduce how users are interacting with viewing friends profiles, commenting on photos and posts, and updating status [8].

The emergence of social systems has expanded the scope of human-centered computing within the greater field of information technology [9]. Data related to user behavior patterns is recorded within web systems and such are used in their analysis, design, and improvement. Behaviour pattern data is an essential part of the software lifecycle. The value of Internet projects in terms of commercial potential and growth opportunities is underpinned by heavy user numbers [10]. Research in the sector is vital to ensure greater system usability, user experience improvement. Research also supports both technical and economic system efficiency enhancement, while retaining practical usefulness for consumers.

In such a context, the series of thematically-related publications is aimed to provide a response to new research trends and challenges that have emerged in recent years. The main purpose of the thematically-related publications was to be a catalyst in the development of solutions oriented towards the modeling of internal space online social systems. Structurally, when considering online social systems, internal, external, and border spaces can be considered. The schematic structure of the online social system taking into account the division into the three spaces mentioned together with the related research areas is shown in Figure 1.

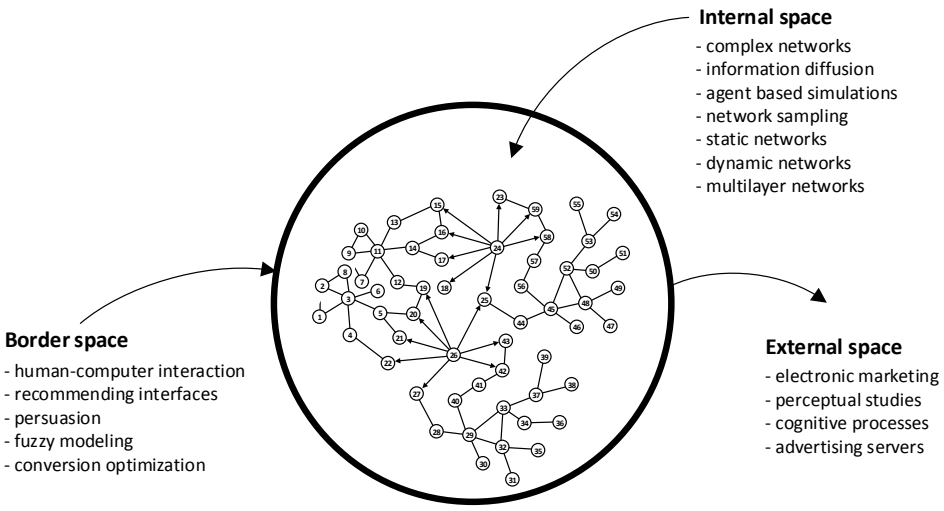

Fig. 1. Structure of the online social system with division into internal, border and external space

The presented cycle of thematically related publications focuses on the internal space of social platforms, based on the structures of social networks used as a medium for the propagation of information, virtual products and other content. The complexity of phenomena within social networks justifies research aimed at acquiring knowledge about their specifics as well as research that introduces new analytical approaches. The modeling of internal space social networking systems with the use of agent based systems and simulations is intended to reflect the involved phenomena, for example to increase the dynamics and extent of information diffusion processes, increase their efficiency, study computational complexity, verify algorithms before applying in real systems and better understand phenomena occurring within them. The presented research focuses on information dissemination processes that underpin the functioning of social systems. Complex networks are the medium for transmitting content on social networking platforms and other computer systems. Information dissemination processes are an often overlooked basis for political change [5], emotional events [12], diffusion of innovation [11] and other initiative such as viral marketing [3]. Content delivered through electronic systems include text [13], video [14], photos [15], marketing messages [16] as well as information concerning disseminations processes. Research in the area is interdisciplinary drawing interest from scientists with background in computer science and computational network science.

From a scientific perspective, the challenges in the field of computer science include the selection of influential network nodes [34][21], models of information flow in complex networks [17], analytical models that identify factors influencing process efficiency [20], impact maximization [18][24] and analysis of phenomena related to propagation of behavior on the Web [19]. Problems identified in the area issues many computational challenges and are treated as NP-difficult problems [25]. The intentional initialization of information propagation processes is based on the selection of the initial nodes for triggering information cascades within the network. Selection of triggered nodes is referred to as seed selection problem, which is then used to initiate the propagation of information [31]. Choosing an initial set involves high computational costs. There are approximate

solutions based on the greedy method [25], its extensions [27], data mining techniques [26] and combinatorial approaches [22][23]. Heuristics are often used on the basis of centrality measures such as vertex or proximity, for which there is high transmission potential [28]. Research in the field employs, inter alia, agent simulation models [29] that allow for verification of new solutions and the determination of the impact of factors such as network characteristics or propagation mechanisms on the dynamics of information spreading [30].

Most of the earlier studies consider seeding in a single step, and the selection of initial nodes occurs only at the beginning of the process. After their selection, the information continues to spread through the use of natural diffusion mechanisms without additional support. For modeling of propagation of information epidemiological models such as SIS, SIR and their extensions are used [33] as well as independent cascade models [25], branching processes [32] and linear threshold model [25]. In addition to the single step approaches, work has recently been developed based on an adaptive solutions in which knowledge accumulated during the process is used to improve its parameters [35]. Other approaches include parallel processes and interaction between them [37], most often in a form of competing cascades [36].

Recent research in the area is geared towards optimizing the use of seeds and reducing the number of selected nodes in the same network segments. The solutions are based, for example, on the use of voting mechanisms with assumed lower weights for neighboring nodes, as well as increasing the number of active nodes in the immediate vicinity [39]. Another solution to the problem is the K-shell algorithm. The algorithm is based on the identification of central nodes, which provides better results than the node degree based measures [40] and the other possibility is restricting node selection within the same community [38]. The solution contributes to a better use of the initial sets and increases the range of the process at the same cost, i.e. the number of nodes activated within the initial set.

This research direction is one of the areas of research that allow for better use of natural diffusion processes with sequential approach [**A1**]. The first sequential seeding research results were the basis for a series of work orientated on the development of new algorithms and methods for initiating diffusion processes. The focus in such studies was on solutions based on the assumption that improvement can be done at the expense of extending the process time then compared to one stage based solutions. Various types of approaches and best practices were tested in the developed sequential seeding algorithm, which differs from the algorithms used in the area so far. The solutions developed were considered a compromise between the duration of the process and the reach within the complex network represented by the number of activated nodes. A range of algorithm variants have been verified throughout the studies. While the basic version assumes unconditional seed sequencing regardless of the state of the process, an extension is also proposed in the form of a revival mode algorithm, where the use of additional activation occurs only when the process expires. Algorithms were verified with the use of agent simulations with the use of independent cascades model [25]. They were also verified on real data sets of complex networks with varying process parameters and number of nodes selected for the initial set. The algorithms were compared to existing approaches based on the centrality measures and the VoteRank algorithm [39] as well as the community-oriented solution [38]. The results confirmed the improvement of outcomes compared to the previous methods. In more than

90% of simulation runs, sequential solutions provided better results based on centrality measures such as degree or closeness than single step solutions. The potential of the developed solutions is based on better utilization of natural processes of information dissemination as well as reduction of resource consumption on node activation, which can be activated by other nodes in the natural process. Delayed use of initial nodes resulted in improved reach, but also increased the duration of the process. Simulations were based on different activation numbers at each sequence step allowing for the detection of dependence between the coverage and the duration of the process. The greatest reach was obtained with maximum decomposition of the process and activation of only one node at each step. At the same time, it resulted in the greatest duration of the process. The best results in terms of reach were obtained for the algorithm with the revival mode and re-initiation of stopped process, but its use further increased the duration of the process. Additional algorithms focused on research related to impact of buffering and resuming processes on their reach and execution time. Algorithm with process revival ensures the greatest range, but at the same time increases the duration of the process. Buffering enables the process to be conducted in close time to sequential seeding without resuming and is a compromise solution that provides a range less than the resumption. Simulations have allowed the determination of the relationship between increases in coverage and process duration. The results indicate the usefulness of buffering, which has a minor effect on the deterioration of the results while significantly reducing the process.

In the basic sequential algorithm, node selection at each step is based on a ranking determined by the network metrics calculated at the beginning of the process. Such may lead to the situation where nodes with high diffusion potential and high degree, lose their potential as a result of the activation of adjacent nodes. Due to their high static rank they are selected as seeds in subsequent sequences. In the next solution included in the publication [**A2**], an algorithm was proposed using effective measures where only nodes inactive in a given stage of the process were considered. Only nodes from the neighborhood that have not yet been activated in the natural process or during seeding are considered when determining the dynamic degree of the node. Similarly, the determination of the effective measure can be performed at a dynamic degree of the second level, taking into account the number of neighbors and the total number of their neighbors (DD2), and similarly for other network measures. Under the same conditions, the use of dynamic rankings improved the number of network activations in more than 80% of configuration variants. Recomputation of network metrics at each stage of additional seeding increases the complexity and the need for additional computational resources. The study analyzed the recomputation time of the network measures and the obtained data allowed to determine the relationship between the increase of the range and the increase of the recalculation costs. In simulation experiments, various propagation parameters were investigated, the intervals between the conversion of network measurements and their influence on the range of the process.

Another element of novelty in the conducted research was the consideration of additional impact on the information dissemination process already after its initiation by a supporting seeding [**A3**]. The research involved initiating the process using one stage based methods and additional support by activating selected network nodes during the process. The developed algorithm uses up-to-date data from the propagation process and makes additional node selection based on their measure of centrality. The research verified the operation of the algorithm in the experimental space, taking into account the various

probabilities of propagation. Process support levels were set from 10% to 100% of the initial set. The research allowed the measurement of the effectiveness of different levels of support represented by the increase in the number of additional network activations per supporting unit. The largest gains were observed with the support of 10% - 30% of the initial seeding. Increasing the impact of more than 30% of the initial set resulted in inferior outcomes and was less justified.

Previous research related to initiating information diffusion processes in complex networks has been based on homogeneous sets of initial nodes. Such are selected using one of the selection methods; for example, according to the ranking based on degree or other centrality measure. While each measure represents specific network properties, a homogenous set of initial nodes can lead to overrepresentation of nodes with specific characteristics. At the same time, selection of the initial set of nodes, for example with a high degree, contributes to the selection of nodes that can be associated with other nodes from the initial set. Inclusion in initial seed is not necessary as they are likely to be activated in the natural propagation process. The implications is a better use of resources and leading to a search for further solutions. In research [**A4**], an attempt was made to reduce the problem while maintaining the efficiency of the process. Efficiency was measured by the number of network activation by applying optimized blends that used a set of nodes with mixed characteristics with different nodes of specific properties, e.g. 25% of nodes in the generated ranking are based on the vertex degree, 25% according to the closeness and 50% in the measure of betweenness. The use of mixtures made it possible to achieve a more diverse set of target nodes without overexploiting nodes with specific characteristics. At the same time, the use of mixtures did not affect the performance of the process represented by the number of nodes activated within the network. Mixture based solutions were verified using agent modeling and experimental plans for particular parameters of the experimental space, i.e. network type and propagation parameters.

Apart from static network research one of the current directions of research is based on dynamic networks, where representations taking into account temporal aspects provide a description of a more similar to the reality [47]. The problem of choosing initial nodes is complicated by the variability of network properties over time resulting from the variable number of nodes and edges. It is then difficult to appropriately allocate resources and select nodes when initiating information dissemination processes. Most of the available initial node selection strategies are based on static centrality measures such as vertex, proximity, or clustering. In the past research related to seeding strategies the role the availability of nodes for dissemination of information on the network was not taken into account. The problem occurs in social platforms, where for the dynamics of the process of information dissemination key are the users' logins and active usage of the system. The propagation potential of the system user with a high degree; however, with a low frequency of use of the system may be small. In work [**A5**], attention was paid to the possibility of using nodes with high activity with worse network parameters in propagation processes, where propagation potential is larger than nodes with large measures but with lower activity. According to the Authors it is one of the first papers dealing with the issue of seeding in dynamic networks. Simulation studies carried out in the agent environment gave the possibility of defining the mechanisms of centrality measures and measures of activity. The proposed solution contributed to balancing the network by minimizing the use of key nodes with high centrality measures for nodes less important for centrality but with higher activity rates. The study was

conducted using theoretical network models such as the Barabási-Albert [44], Erdős-Rényi [46] model, and the Watts-Strogatz small-world phenomenon [45] model. The results showed that in the Barabási-Albert network, the set of nodes defined by the central measure can be compensated by two times larger set of nodes with lower central values but with greater network activity. The article also proposes vector seeding, where the initial node selection is the maximum value vector for each of the network measures taken into account, and then for each candidate node an Euclidean distance metric is determined. Research has shown that vector strategy in dynamic networks is superior to classical methods based on individual measures.

The problem of information propagation was also considered in connection with knowledge diffusion processes [**A6**]. Within the social networks there is a flow of expert knowledge, knowledge of products or knowledge associated with the organization's activities. Corporate social platforms are used to promote knowledge and improve the organization. Modeling of the phenomena involved in them required new solutions. The cognitive and emergent effects associated with the common knowledge acquisition are included in proposed model. It takes into account the role of moderator and the allocation of expert roles. The algorithms enable new links on network to influence the competences of community members. The research developed a mathematical model of knowledge flow and verified it in simulation environment using theoretical models of networks. The analyses were subject to processes that were the result of the strength of particular nodes or influence of network segments on knowledge resources. Research has shown that over-supplying knowledge into the network can lead to the unused potential of the allocated knowledge resources and often translates into ineffective propagation processes related to forgetting or mismatching of competency patterns among broadcasters and receivers.

In addition to the spread of information in single-layer networks, the current direction is also the diffusion of information in multilayer networks [42]. In real systems, relationships are created in multiple layers, and they often involve layers of personal, professional, or social communication. Taking into account such specifics, the performed research gives the possibility of better reflecting on the theoretical phenomena in reality. The cycle of thematically-related publications also includes research in this area [**A7**]. The developed model takes into account the specificity of intra-layer and inter-layer diffusion, and extends typical models of knowledge flow into a multi-layered approach whereas previous models focused on diffusion of knowledge in one layer. From an organizational perspective, combining several types of knowledge and modeling the change of competencies by layer is a solution that better reflects the specifics of real processes of knowledge flow. Another element of novelty is the consideration of processes involving horizontal diffusion within the one layer and the vertical diffusion between the layers.

The research conducted on complex networks and social platforms has highlighted a number of problems related to the analysis and processing of large data sets. The question arises whether, for the purposes of research, it is possible to use network samples instead of complete data sets. The properties of the network sample should be similar to the characteristics of the output network for the purpose of analyzing the characteristics of the dissemination of information. Available network sampling methods provide the generation of representative samples in the form of smaller networks with similar characteristics to the primary network, but usually with the overrepresentation of the nodes with the highest

network parameters. Work [**A8**] proposed a balanced approach to network sampling, which focuses on obtaining a sample with predetermined network parameter distributions. The proposed algorithms use the evaluation function and the quality evaluation of the sample. The derived structures on the basis of the output network have similar distribution of parameters used in the selection of initial nodes and characteristics similar to the primary network.

Subsequent works in the series of publications refer to the classification of ACM in the category of research related to the design of human-computer interactions and studies of users of information systems. Research has used the virtual world as a platform for experiments in the diffusion of information. Developed programming solutions have enabled the integration of digital content diffusion mechanisms and monitoring of information dissemination processes. Real process analysis has provided the basis for a model that reflects the structure of information cascades, taking into account individual activation levels and their generation characteristics. The article [**A9**] presents a generation-based solution that deals with activation levels taking into account the hierarchy of relationships, not just the time factor as is the case in most analytical models. The generation dimension provides additional analytical capabilities with the structure of node activation, information cascading levels and their quantitative parameters, which translates into knowledge of the process and its dynamics. In the test data, the process data was used at different stages of its implementation and the model accuracy was analyzed. It increased with the acquisition of process data. The novel element is a microscopic analytical approach based on the hierarchical structure of cascades and not only on aggregated macroscopic data.

The purpose of further research was to analyze the influence of digital content parameters and propagation mechanisms on the dynamics of information dissemination processes. Work [**A10**] examined the different characteristics and mechanics of information dissemination processes in a social platform. A low transmission barrier defined as Low Resistance (LR) and a high transmission barrier as High Resistance (HR) were isolated. As a methodological basis of analysis, the branching processes and the proposed earlier generation approach for modeling information cascades were used. Based on the recorded data for individual experiments, the propagation parameter p was determined, which specified the probability of transmission, the epidemic intensity parameter λ, and the epidemic threshold (ETP) defined as $p * \lambda$. According to [41], the relationship between parameters is defined as subcritical when $ETP < 1$, supercritical for $ETP > 1$, and critical for $ETP = 1$. Experiments have provided theoretical results relevant to the study of human-computer interactions and the linking of technical mechanisms of content propagation to user characteristics. The analyzes introduced conversion factors and measures of commitment to reflect the quantitative characteristics of the studied phenomena. The obtained results indicated the key contribution of the visual factors of the transmission, which had a greater influence on the transmission dynamics than the parameters of the senders and receivers. The analyzes include the multilayered nature of social networks, broken down by communication, transactional and social layers. The results suggest a key role of the product presentation phase, which reinforces the diffusion processes based on textual communication. The outcome reflects real-world processes in which the dissemination of information can be related to the actual presentation of the product or can only be based on a verbal description. Literature analysis has shown that there are no studies of this type in the digital environment. The results indicate the low effectiveness of propagation of

products distributed in the Low Resistance model due to the lack of social relations and interactions on the sender-receiver line. Despite the potentially large number of transmissions, the conversion and engagement parameters were relatively low at such transmissions. The resulting solutions may provide the basis for a compromise between high-dynamic transmission and lower efficiency to increase transmission barriers, and translate this into stronger relationships between receivers and broadcasters. In addition to the scientific aspect, research results may be used by Internet system operators to design mechanisms related to digital product promotion whose increasing market share is highlighted in numerous studies [43].

The interdisciplinary studies presented in the paper [**A11**] have been conducted to better understand phenomena occurring in social systems that affect the dissemination processes. The purpose of the study was to monitor and analyze the factors that influence the construction of social bonds and the impact on social platforms. The combination of computer science and sociology enabled the planning and implementation of measurement systems in an online platform focused on monitoring and recording social networking events. In addition to the sociological relevance of preferential attachment and the generalization of relationship theory, the project has provided results that are interesting for the design of social platforms. The outcomes included scenario planning and user segmentation involving gamification and the design of virtual products or subscriptions.

Further research into the operation of social and distribution systems by [**A12**] was related to the digital products and digital product diffusion between users. The purpose of the study was to model the characteristics of users performing transactions related to the purchase of digital products within a social platform. For the purpose of constructing the inference system, the neuro-fuzzy ANFIS model which integrated with the transactional databases of the system, was used. The study adopts a macroscopic approach including aggregated transaction data without analyzes at the level of social network structures. The result of the work are two fuzzy inference models that are oriented on user characteristics of transactions and the characteristics of users who make decisions about the transmission of virtual objects and initiate propagation processes within the network.

Work [**A13**] proposed to model user activity in two time dimensions. For the purpose of determining the activity parameters, a bi-temporal representation of the time representation of the events was recorded in real time and virtual time. The approach enabled the representation of the activities and engagement of users of social networks.

Contribution to the computer science discipline

The work was conducted in relatively new areas that acquired focus of research community in last decade. The development of social platforms and the evolution of web based systems in this direction raised a number of research challenges related to their modeling, optimization and exploitation. Numerous scientists point the research potential of social systems and there is a significant share of the number of computer science publications in related fields. For example, for the keyword "*influence maximization*" in SCOPUS database 566 publications are registered and 475 of them are classified in the discipline of computer science, for *“viral marketing”* 791 of 499 is related to IT or in the wider context of "*social network analysis*" from 9826 papers 4949 are classified in computer science and only 2847 in social sciences.

The presented research has made a significant contribution to the development of the computer science discipline in accordance with the ACM classification of Human-centered Computing, with particular emphasis on areas related to social computing such as Social Networks, Social Media, Social Content Sharing, Collaborative Content Creation, Human-Computer Design and Evaluation. Associated areas are related to User studies, User models, Web-based interaction and Virtual reality. The proposed models and experimental research have contributed to a better understanding of the phenomena taking place in online social systems and the development of science in this field. In particular, the results of the work are new methods oriented towards the modeling and exploitation of social networking sites, which have allowed the development of methods of designing and analysis of Internet systems. Results make a significant contribution to the emerging computational network science. It is a new field that supports the analysis of natural and artificial systems, the study of the relationship between the network components and the networks [1]. The basis is an algorithmic approach that has helped to unify the methods used to analyze networks in different areas.

Considered in the series of thematically-related publications, the internal exploitation of social systems is based on exploiting the potential of social networks and mechanisms of information flow. The study [**A1**] conducted in the area have introduced new algorithms oriented at the sequential activation of nodes in the network while initiating information diffusion processes. The studies were the basis of comprehensive research that showed an increase in efficiency compared to the one-step algorithms used in earlier solutions. The highest efficiency and potential utilization of natural diffusion mechanisms provided algorithms for triggering extinguished primary processes and with buffering approach. Solutions based on dynamic rankings [**A2**] contribute to the study of the relationship between computational complexity and system efficiency, in which network structures play a central role. The research has made it possible to better understand the dynamics of phenomena occurring in complex networks and their results have the potential to be used in modeling the systems for which information flow is important. The presented solutions for sequential selection of nodes initiating information dissemination processes are the methodological basis for compromise solutions in which it is possible to balance between the range and duration of the process or the reach and the computational complexity.

The results obtained have a potential for development and indicate new directions for complex network research and ongoing processes. One is proposed supporting seeding algorithm, where the impact on the process is realized through additional node initialization [**A3**]. The approach is new in a field of research, where work has so far focused mainly on the main process. In real systems, the diffusion of information is not usually isolated and there are external effects associated with, inter alia, activation of additional nodes, for example in marketing. More extensive research in this area is currently underway within the framework of managed by my grant founded by National Research Centre. An alternative to homogeneous selection of nodes in networks proposed mixture based model provides the opportunity to differentiate the initial set and determine the different proportions and characteristics of the nodes initiating the diffusion process [**A4**]. The implemented research is also a methodological contribution in the area of dynamic systems and networks with time varying structures. Currently, it is one of the leading fields of research into complex networks. The compensation proposed in [**A5**] is one of the first concepts to examine the selection of nodes initiating processes in a dynamic network environment.

The work carried out is widely regarded as having brought about new theoretical solutions in the field of collaborative knowledge processing, selection of nodes and their supply of knowledge to increase the efficiency of knowledge propagation [**A6**][**A7**]. The proposed models of knowledge transfer and acquisition in networks introduce new dynamic models of competence and knowledge dissemination processes in the agent based system. The novelty is a model of knowledge diffusion processes in a multilayered approach with horizontal and vertical diffusion as well as self-learning and forgetting mechanisms implemented. Previous models were based on a one dimensional view with only one type of knowledge included. Developed agent models provided analysis and tracking of knowledge dissemination and empowerment in the network, the ability to assign roles to the network, and streamline knowledge flow in groups.

Contribution to the development of computer science is the proposed approach of adaptive sample generation of networks, which is oriented on matching the given network distributions determined from the full network [**A8**]. The proposed solution enables impact on a sample of the network by attaching or eliminating nodes while evaluating and minimizing the distance of the sample characteristics (network parameters distributions) from the primary network characteristics using the Kullback-Leibler measure. One possible implementation of the new approach is the proposed K-bins algorithm, which generates a target data set with minimized distances from the primary set on the basis of set sample members' characteristics.

Research on the use of generations and branching processes in the analysis of information dissemination mechanisms provides a new analytical method that takes into account the hierarchical structure of network propagation [**A9**]. The methods used so far provide time and range analysis and do not reflect the hierarchical levels associated with information cascades. Data analysis from each level provides additional insight into the dynamics of the process and its quantitative characteristics. The proposed approach approximates the process to the calibration curve, whose shape and accuracy depends on the number of steps to be analyzed.

The results presented in [**10**][**11**][**12**] related to real system experiments are relevant to recent developments in the area of gamification, which aims to integrate mechanisms in the design of systems that increase engagement and loyalty. The studies also refer to the role of user status indicators in a system that grows with the activity and time of the system and the relationship between the freemium model and the paid products and services. The study also addresses the area of the rapidly growing virtual products market for which development is key in the field of information technology related to usability, human-computer interaction and system design. The studies were carried out in cooperation with recognized experts in the field. The work [**A10**] contributes in the area of social content sharing and human-computer interaction related to the identification of the influence of digital content transmission mechanics on their propagation processes. Experiments have made it possible to compare the dynamics of processes in which the recipient was subjected to the visual impact of transmitted content with processes in which the effects were verbal only. Research fits in with the trend of using virtual worlds as laboratories where you can study phenomena difficult to monitor in the real world and human-computer interaction [2]. Work [**A11**] is a contribution to the areas related to human computer interaction (in the User studies and Virtual reality categories). It shows the significant influence of the design

elements of the system in the context of the visual layer on the dynamics of communication processes. Work [**A12**] points to new uses of fuzzy models in the area of social content sharing and their integration with real social platforms. According to the Authors knowledge, it was the first solution that integrates fuzzy inference patterns with transactional data associated with the digital product distribution platform.

Internal state analysis of the system is not only related to the structure of social networks but also to patterns of behavior of users. In research [**A13**], behavioral modeling has been proposed, taking into account the two dimensional time lapse model, oriented on real time and virtual time. The proposed approach enables monitoring of behavioral changes and state prediction based on the introduced distance function that determines the relationship between real time and virtual time. The decline in activity within the system affects the increase in disproportions that are aggregated over time to a single distance measure.

In summary, presented in the current cycle of thematically-related publications "Modeling of internal space of online social platforms" is research which has allowed better understandings of complex online social systems. The research has introduced algorithmic and analytical methods to model phenomena occurring in social systems. Most have wide ranging applications in modeling systems where complex networks and information dissemination processes are involved or supporting the design and operation of online social platforms.

Summary

The most important scientific achievements presented in the series of thematically-related publications contributing to the development of computer science are:

• developing sequential seeding algorithms in a generic, revival and buffering mode [**A1**] that point to a new direction of research based on a single stage approach and provide more nodes activation than previously used algorithms with the same number of initial seeds,

• research related to the impact of the increase in reach on extending the duration of information dissemination processes [**A1**] and developing algorithms based on dynamic rankings and determining dependency between process reach and computational cost [**A2**],

• research on the impact of processes supporting the primary information dissemination process [**A3**] and the development of assistive algorithms and algorithms using mixed models for initial node selection and the pursuit of sustainable solutions [**A4**],

• development of a compensatory seeding concept in dynamic networks based on node activity parameters and verification of basic and vector algorithms on theoretical network models [**A5**],

• mathematical model of collaborative knowledge dissemination in the social network including community detection and competence vectors [**A6**] as well as multilayered knowledge diffusion in complex networks[**A7**],

• network sampling method and algorithms based on the minimization of the distance of the sample’s network measurements from the primary network taking into account the

possibility of influencing the trajectory of the sample in the assumed range of values determined by the aggregated distance values [**A8**],

• study of real information dissemination processes and development and validation of the method of generations based analysis of information dissemination processes for complex networks [**A9**], identification of the influence mechanisms and the role of visual factors on the dynamics and extent of diffusion processes [**A10**],

• research into the preferential attachment [**A11**], and development of fuzzy models for capturing user behavior associated with digital products [**A12**] and analysis focused on real and virtual time [**A13**].

In addition to the research and theoretical aspects, the results obtained are applicable in a range of fields. Sequential seeding along with coverage extension is a meta method that can be used in many practical areas. In technical systems, the sequential initiation of information propagation processes provides the opportunity to reduce the use of computing resources and to better utilize the bandwidth limits. In the case of electronic marketing, a sequential approach can reduce the negative impact on users of mass communications by sending large amounts of messages for better resource allocation and relying on natural diffusion processes. The economic efficiency of the sequential approach and the better use of available budgets in marketing activities are also important. Research results can also be used in the context of emergencies and the propagation of information where it is important to maximize the number of target recipients. The results provide guidelines for the design and operation of interactive systems, taking into account the specification and expectations of their users. Research into the actual propagation of virtual products, their propagation mechanisms, and user characteristics has provided new insights into the functioning of these systems. Experiments related to the role of avatars and visual representation of users, status or characteristics of virtual products as well as dynamics of social relations are the basis for efficient design and operation of systems [**A10, A11, A12**]. The economic potential and dynamic development of social platforms, virtual goods and massively multiplayer online (MMO) based social gaming platforms determine the need for further research into the direction I plan to pursue.

The work was partially performed in cooperation with researchers from other universities. Research in [**A1-A5**] was carried out in cooperation with scientists from the Wrocław University of Technology and Rensselear Polytechnic Insitute, Troy, USA, works [**A8**][**A11**] with scientists from Wroclaw University of Technology and Knowledge Media Research Center, Tübingen Germany, [**A10**] in collaboration with Game Research Lab, University of Tampere, Tampere, Finland and [**A12**] in collaboration with The University of Thessaly, Volos, Greece.

Other research activities

The subject of the other papers published after obtaining the degree of doctorate in the discipline of computer science encompasses the study of social systems, their modeling and their effectiveness. **The list of publications referenced in this section is located in Appendix 3**. In investigations related to the internal space of social systems, buffering and revival methods for seeding were further analysed [13]. Other research analysed the influence of the parameters of receivers and broadcasters on the level of dyads on diffusion efficiency [22]

taking into account the role of parameters connected with social network activity in the diffusion process. Further studies in the area were conducted on the basis of multilayer networks, and they were oriented on the analysis of diffusion processes in intra group and inter group setup in real networks [23] as well as the setting of threshold values which exceeded the rapid increase of dynamics of diffusion processes within the complex network [24]. The study also included analyzes of multilayer network structures for the presence of different communities in different layers of the network, which may lead to difficulties in using existing algorithms to detect them [21]. The research carried out modeled multi-stage data processing mechanisms in diffusion processes, divided into phases of interest in transmission, its absorption and transmission to other network nodes. The developed multi-stage model has made it possible to better understand the phenomena and extend the models available so far to take into account the characteristics of the transitions between node states [25]. As a part of the research of real processes, the relationships and functions of transition between the stages, which state the measure of the efficiency of mechanisms used in the distribution of information in complex networks, were determined.

Another area of research was related to the virtual products sector distributed within social systems. Surveys conducted in the area include a system for monitoring transactions and dynamic valuation of digital products tailored to the purchasing power of users and digital behavioral surveillance [19]. Research and experiments have enabled the determination of the impact of user characteristics on their behavior within the system. A research summary in the area was the development of an encyclopedia entry related to virtual products [78].

Research on the spread of knowledge in social networks has been linked to the development of assumptions for the dynamic management of competencies [20]. The research also considered recommended algorithms in the context of integrating data from social networks and generating recommendations based on relationships [27]. As part of the work, a method of network acquisition based on sampling [28] has also been developed.

The research was also concerned with the usability of web sites and was conducted in the context of the selection of methods for their evaluation and management of domain knowledge in this area [39]. Introduced solutions enable to build a knowledge base of the domain, which facilitates the selection of methods of evaluation of websites. The method of selection of criteria and selection of weights in the evaluation process of web projects was also part of the research [34]. On the basis of the proposed solution, the usability studies of Internet portals were carried out. The methodological bases of the proposed solutions were multi-criteria decision support methods, which proposed an approach based on the description of the unstructured decision problems. Another work presents a method of selecting criteria and determining weights in the evaluation process of websites [40]. Also included in the repository of domain ontologies was the Web site evaluation method, which included the space of the system evaluation parameters used in leading methods [36]. The research on the usability of websites at work [37] presents a method based on the determination of evaluation criteria of the highest relevance to the decision maker. The construction of a repository of knowledge related to web site evaluation methods was also part of the study [38].

The work carried out in the earlier periods referred to the current development trends of Internet systems and influenced the development of later research interests. Once the development of electronic media has identified the direction of the development of Internet

systems linked to increased participation of social solutions [72] and their gradual evolution in this direction [60]. The specificity of the first social platforms pointed to the possibility of implementing new marketing solutions [57]. The subject of implementation of marketing activities in social networks was also considered taking into account factors of uncertainty [75]. The work involved topics related to the modeling of information flows in social networks and the analysis of available solutions, as well as the development of the micro-finance and virtual goods sector in social platforms and virtual worlds. One of the topics was also identifying the factors influencing the success of marketing in virtual worlds [61]. It was proposed to integrate affective approaches and emotional measurements in social media platforms [74] as well as an alternative approach to classification of content with collaborative selection in Web 2.0 applications [81]. The concept of moving Web 2.0 paradigms to the local government platform [71] is also presented. The growing need to design the information architecture because of difficulty of accessing such using classic interfaces with hierarchical content access was discussed [76]. As part of the work, solutions were implemented to monitor the dissemination of marketing information [58]. One of the effects of the practical work was the agent system of monitoring electronic markets [73]. The subject of applications of decision support systems in e-commerce [77] was also discussed.

Apart from research activities in the scientific discipline of computer science, some of my scientific achievements, mainly earlier, are related to balanced approach to electronic marketing, marketing communication efficiency, perceptual research, invasive marketing communication, persuasive interaction and the economics of online systems. These works are discussed here as elements of the whole scientific activity, but are not related to presented scientific achievement in computer science. In [41] work, eye-tracking was used to determine the characteristics of visual pathways, areas of interest within the marketing and editorial sections. The subject of the study was the exploitation of web based resources for increasing conversions and economic effectiveness [47]. Research proposed dynamic changes of the level of impact on the recipient during re-exposure of the marketing message [45]. Research relates to the current trend of optimizing conversions in marketing and generating specific interactions. The proposed solution is to limit the negative impact on users by seeking a balanced solution and determining the level of saturation, after which no improvement in conversion is observed and there is an increase in negative impact [46]. A media model was developed to reduce the invasiveness of advertising components [48] and a model of optimization of advertising activities, taking into account the results of perceptual research and online experiments [9]. In empirical research, experiments have been conducted with the decomposition of the marketing message into sub-elements and the automatic generation of design variants associated with the effects measurement. Work [56] proposes a multi-stage method for increasing the effectiveness of marketing activities, which uses factor analysis and dynamically generated design variants. Work [44] focused on the interaction between graphical components and text elements, including mechanisms for limiting the role of text with increased interaction of graphical components. Research has also highlighted the negative impact that social media users have on the diffusion processes associated with the dynamics of their actions [26].

In work [54], eye-tracking studies were conducted on the impact of marketing message characteristics on user behavior. The article [42] presents the results of an experiment that aimed at identifying EEG patterns of brain activity during interruptions of cognitive processes

generated during the processing of marketing content on the website. Within the work, a multi-step model for increasing efficiency in the implementation of marketing activities in the electronic environment [51] has been developed. The concept of dynamic approach with MCDA methods is used to support the optimization of advertising campaigns [50] and the relationship between marketing content and editorial content in the internet system has been determined with the method of multi-criteria decision support COMET [49]. A fuzzy approach to behavior modeling has also been proposed, in which it is possible to set outbound boundaries between the total audience and the target group in order to limit over-specifying transmission parameters and to limit the potential target group [64]. Work [43] presents an inference model that is oriented on the level of persuasive influence on the user of the recommend interface. Research has also proposed the use of collective knowledge in the design of web sites by integrating data from measurement systems into the fuzzy inference model [33]. Other publications include planning marketing activities with taking into account the uncertainty [82] and marketing communications in Web 2.0 applications [57]. The subject of the work also included planning of advertising campaigns in an interactive environment, taking into consideration the characteristics of the interactive message and the differences in the measurement of the effectiveness of activities in traditional and electronic media [63]. Electronic media was considered as an environment with a high dynamics of change, and sources of uncertainty in measurement and in decision-making processes related to audience variability and target characteristics [79] were identified. Also developed were the assumptions of the agent system for the monitoring of search systems and increases in the effectiveness of marketing activities with their use [67]. Adaptive solutions for modeling of interactive content in electronic media have been proposed [80] as well as presented the possibilities of applying factor analysis in personalization of web content [68]. The concept of applying the methods recommended in the production personalization system [68] was also presented. The process of optimizing the structure of marketing content with multivariate analysis [69] was proposed together with identification of factors influencing the effectiveness of marketing activities [70].

As part of the remaining work, the subject of the study was the characteristics of decision support methods, their adaptation to decision problems of a specific nature. The knowledge gained in this study was also used in research related to web based systems. In [53] a set of characteristics for multi-criterial decision support methods has been developed to facilitate their selection for solving problems of a specific nature. The goal of [52] was the method of transforming decision tasks into decision support systems. Knowledge management in decision support methods taking into account the characteristics of decision problems and their applicability to MCDA methods is presented in [29]. In subsequent studies, ontologies were used to represent knowledge related to the specifics of multi-criteria decision support [30]. The use of the AHP method was also investigated in inaccurate expert judgment [55]. Work [31] presents the PEQUAL method, which extends the EQUAL methodology to internet sites with the Promethee decision support multi-criteria method and its use in evaluating auction systems [35]. Other work includes the use of decision support methods and systems in various areas including intelligent supply chains [32]. The expertise in decision support methods was used for the multi-criteria decision support to assess the economic potential of the location of energy sources on the example of wind turbines [11].

Summary of scientific achievements

Since obtaining a PhD degree (Appendix 3), I have authored and co-authored 82 published papers. In total, 27 of the publications are independent work. Of these, 12 are published in journals in the Journal Citation Report (JCR) with Impact Factor. Table 2 lists the bibliometric indicators of the overall research activity after obtaining PhD degree (based on the **Annex 3**).

Tabela 2. Bibliometric indicators of the overall research activity after obtaining PhD degree

Name of the indicator	**Value**
Number of publications in journals with Impact Factor	12
Total Impact Factor	24.34
Index H by Web of Science	6
Index H by Google Scholar	10
Number of citations Web of Science without auto-citations	51
Number of Google Scholar citations without auto-citations	97
Number of publications indexed in the Web of Science	46
Number of publications at international conferences	37
Number of publications from list B	16
Number of chapters in monographs	7
Total number of ministerial points	1091
Number of ministerial points with my share	524.8

Bibliography

1. Hexmoor, H. (2014). Computational Network Science: An Algorithmic Approach. Morgan Kaufmann.
2. Bainbridge, W. S. (2007). The scientific research potential of virtual worlds. *science*, *317*(5837), 472-476.
3. Chu, S. C. (2011). Viral advertising in social media: Participation in Facebook groups and responses among college-aged users. Journal of Interactive Advertising, 12(1), 30-43.
4. Ellison, N. B. (2007). Social network sites: Definition, history, and scholarship. Journal of Computer-Mediated Communication, 13(1), 210-230.

5. Bond, R. M., Fariss, C. J., Jones, J. J., Kramer, A. D., Marlow, C., Settle, J. E., & Fowler, J. H. (2012). A 61-million-person experiment in social influence and political mobilization. Nature, 489(7415), 295-298.
6. Bello-Orgaz, G., Jung, J. J., & Camacho, D. (2016). Social big data: Recent achievements and new challenges. Information Fusion, 28, 45-59.
7. Giri, K. J., & Lone, T. A. (2014). Big Data-Overview and Challenges. International Journal of Advanced Research in Computer Science and Software Engineering, 4(6).
8. Russell, M. A. (2013). Mining the Social Web: Data Mining Facebook, Twitter, LinkedIn, Google+, GitHub, and More. O'Reilly Media, Inc.
9. Brown, J. R., van Dam, A., Earnshaw, R., Encarnaçao, J., Guedj, R., Preece, J., ... & Vince, J. (1999). Human-centered computing, online communities, and virtual environments. IEEE Computer Graphics and Applications, 19(6), 70-74.
10. Raice, S. (2012). Facebook sets historic IPO. The Wall Street Journal, (p. A11).
11. Chang, H. C. (2010). A new perspective on Twitter hashtag use: Diffusion of innovation theory. Proceedings of the American Society for Information Science and Technology, 47(1), 1-4.
12. Hoogendoorn, M., Treur, J., van der Wal, C. N., & van Wissen, A. (2010, August). An agent-based model for the interplay of information and emotion in social diffusion. In Proceedings of the 2010 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology-Volume 02 (pp. 439-444). IEEE Computer Society.
13. Bastos, M. T., Raimundo, R. L. G., & Travitzki, R. (2013). Gatekeeping Twitter: message diffusion in political hashtags. Media, Culture & Society, 35(2), 260-270.
14. Susarla, A., Oh, J. H., & Tan, Y. (2012). Social networks and the diffusion of user-generated content: Evidence from YouTube. Information Systems Research, 23(1), 23-41.
15. Wei, X., Valler, N. C., Prakash, B. A., Neamtiu, I., Faloutsos, M., & Faloutsos, C. (2013). Competing memes propagation on networks: A network science perspective. IEEE Journal on Selected Areas in Communications, 31(6), 1049-1060.
16. Domingos, P. (2005). Mining social networks for viral marketing. IEEE Intelligent Systems, 20(1), 80-82.
17. Kossinets, G., Kleinberg, J., & Watts, D. (2008, August). The structure of information pathways in a social communication network. In Proceedings of the 14th ACM SIGKDD international conference on Knowledge discovery and data mining (pp. 435-443). ACM.
18. Mossel, E., & Roch, S. (2007, June). On the submodularity of influence in social networks. In Proceedings of the thirty-ninth annual ACM symposium on Theory of computing (pp. 128-134). ACM.
19. Centola, D. (2010). The spread of behavior in an online social network experiment. science, 329(5996), 1194-1197.
20. Ho, J. Y., & Dempsey, M. (2010). Viral marketing: Motivations to forward online content. Journal of Business research, 63(9), 1000-1006.
21. Kiss, C., & Bichler, M. (2008). Identification of influencers—measuring influence in customer networks. Decision Support Systems, 46(1), 233-253.
22. Ackerman, E., Ben-Zwi, O., & Wolfovitz, G. (2010). Combinatorial model and bounds for target set selection. Theoretical Computer Science, 411(44-46), 4017-4022.
23. Chiang, C. Y., Huang, L. H., Li, B. J., Wu, J., & Yeh, H. G. (2013). Some results on the target set selection problem. Journal of Combinatorial Optimization, 25(4), 702-715.
24. Morone, F., & Makse, H. A. (2015). Influence maximization in complex networks through optimal percolation. Nature, 524(7563), 65-68.
25. Kempe, D., Kleinberg, J., & Tardos, É. (2003, August). Maximizing the spread of influence through a social network. In Proceedings of the ninth ACM SIGKDD international conference on Knowledge discovery and data mining (pp. 137-146). ACM.
26. Chen, W., Yuan, Y., & Zhang, L. (2010, December). Scalable influence maximization in social networks under the linear threshold model. In Data Mining (ICDM), 2010 IEEE 10th International Conference on (pp. 88-97). IEEE.

27. Goyal, A., Lu, W., & Lakshmanan, L. V. (2011, March). Celf++: optimizing the greedy algorithm for influence maximization in social networks. In Proceedings of the 20th international conference companion on World wide web (pp. 47-48). ACM.
28. Chen, W., Wang, Y., & Yang, S. (2009, June). Efficient influence maximization in social networks. In Proceedings of the 15th ACM SIGKDD international conference on Knowledge discovery and data mining (pp. 199-208). ACM.
29. Hui, C., Goldberg, M., Magdon-Ismail, M., & Wallace, W. A. (2010). Simulating the diffusion of information: An agent-based modeling approach. International Journal of Agent Technologies and Systems (IJATS), 2(3), 31-46.
30. Bampo, M., Ewing, M. T., Mather, D. R., Stewart, D., & Wallace, M. (2008). The effects of the social structure of digital networks on viral marketing performance. Information systems research, 19(3), 273-290.
31. Hinz, O., Skiera, B., Barrot, C., & Becker, J. U. (2011). Seeding strategies for viral marketing: An empirical comparison. Journal of Marketing, 75(6), 55-71.
32. Van der Lans, R., Van Bruggen, G., Eliashberg, J., & Wierenga, B. (2010). A viral branching model for predicting the spread of electronic word of mouth. Marketing Science, 29(2), 348-365.
33. Wang, Y., Cao, J., Jin, Z., Zhang, H., & Sun, G. Q. (2013). Impact of media coverage on epidemic spreading in complex networks. Physica A: Statistical Mechanics and its Applications, 392(23), 5824-5835.
34. Kimura, M., Saito, K., Nakano, R., & Motoda, H. (2010). Extracting influential nodes on a social network for information diffusion. Data Mining and Knowledge Discovery, 20(1), 70-97.
35. Seeman, L., & Singer, Y. (2013, October). Adaptive seeding in social networks. In Foundations of Computer Science (FOCS), 2013 IEEE 54th Annual Symposium on (pp. 459-468). IEEE.
36. Wei, X., Valler, N. C., Prakash, B. A., Neamtiu, I., Faloutsos, M., & Faloutsos, C. (2013). Competing memes propagation on networks: A network science perspective. IEEE Journal on Selected Areas in Communications, 31(6), 1049-1060.
37. Stanoev, A., Trpevski, D., & Kocarev, L. (2014). Modeling the spread of multiple concurrent contagions on networks. PloS one, 9(6), e95669.
38. Zhang, X., Zhu, J., Wang, Q., & Zhao, H. (2013). Identifying influential nodes in complex networks with community structure. Knowledge-Based Systems, 42, 74-84.
39. Zhang, J. X., Duan-Bing Chen, Q. D., & Zhao, Z. D. (2016). Identifying a set of influential spreaders in complex networks. Scientific reports, 6.
40. Kitsak, M., Gallos, L. K., Havlin, S., Liljeros, F., Muchnik, L., Stanley, H. E., & Makse, H. A. (2010). Identification of influential spreaders in complex networks. Nature physics, 6(11), 888-893.
41. Becker, N. G. (1989). Analysis of infectious disease data (Vol. 33). CRC Press.
42. Salehi, M., Sharma, R., Marzolla, M., Magnani, M., Siyari, P., & Montesi, D. (2015). Spreading processes in multilayer networks. IEEE Transactions on Network Science and Engineering, 2(2), 65-83.
43. Huang, E. (2012). Online experiences and virtual goods purchase intention. Internet Research, 22(3), 252-274.
44. Barabási, A. L., & Albert, R. (1999). Emergence of scaling in random networks. Science, 286(5439), 509-512.
45. Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of 'small-world'networks. Nature, 393(6684), 440-442.
46. P. Erdős and A. Rényi, On the evolution of random graphs, Evolution, vol. 5, no. 1, pp. 17-61, 1960
47. Holme, P., & Saramäki, J. (2012). Temporal networks. Physics reports, 519(3), 97-125.